PB-249 115

CONNECTICUT RIVER BASIN PROGRAM. PART III, PHASE I. WATER QUALITY RECONNAISSANCE FOR THE CONNECTICUT RIVER SUPPLEMENTAL STUDY

Environmental Protection Agency
Boston, Massachusetts

March 1975

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle

Connecticut River Basin Program
Part III of Phase I Water Quality Reconnaissance for the Connecticut River Supplemental Study

5. Report Date
March, 1975

6.

7. Author(s)
U.S. Environmental Protection Agency

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

U.S. Environmental Protection Agency, Region I
J.F.K. Federal Building
Boston, Massachusetts 02203

10. Project/Task/Work Unit No.
CRS-NERBC-EPA
1,6B (1,2)

11. Contract/Grant No.
N/A

12. Sponsoring Organization Name and Address

New England River Basins Commission (NERBC)
55 Court Street
Boston, Massachusetts 02108

13. Type of Report & Period Covered
Final

14.

15. Supplementary Notes
Working paper prepared for NERBC Connecticut River Supplemental Flood Management Study, Phase I.

16. Abstracts

A water quality analysis provided an envirionmental sketch of factors primarily responsible for basin water quality. Correlations between flow and 12 parameters indicated that only 10 to 25 percent of parameter variation can be attributed to stream flow. The daily nutrient loads passing Northfield, Mass. were estimated to be between 1,300-8,000 lbs/day for ammonia nitrogen and 9,000-13,000 lbs/day for phosphates; while at Enfield, Conn. the ammonia nitrogen ranged between 13,000-3[illegible],000 lbs/day and phosphates 11,000-30,000 lbs/day. The apparent anomaly indicated in the N:P ratio at the two stations is due to the high levels of ammonia-nitrogen discharged into the river in the Springfield Metropolitan area just above Enfield. Estimated silt losses in the basin range from .75 million - 5 million lbs/day with some areas experiencing serious losses while other areas having little problems. The report describes the physical-chemical changes in water quality which occur as a result of impoundments and presents a bibliography covering the topic. Land use functions in water quality management are discussed and a water quality reconnaissance of six selected tributaries was performed. The tributaries are: the Westfield River, the Deerfield River, Whetstone Brook, the White River, the Ammonoosuc River and the Passumpsic River.

17. Key Words and Document Analysis. 17a. Descriptors

Connecticut River Basin
Water Quality
Stream Flow Effects
Nutrient Loads
Silt Loads
Impoundments
Land Use

17b. Identifiers/Open-Ended Terms

Water Quality Reconnaissance
Impoundment Effects on Water Quality

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement
No restriction. Available from National Technical Information Service.

i.

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
273

22. Price
9.00-2.25

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

015041

PB 249 115

CONNECTICUT RIVER BASIN PROGRAM

Part III of Phase I

Water Quality Reconnaissance for

THE CONNECTICUT RIVER SUPPLEMENTAL STUDY

This study fulfills the water quality information requested in the Supplemental Study Guidelines for the water quality aspects of the environmental reconnaissance section.

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

Prepared for the New England River Basins Commission by
The U.S. Environmental Protection Agency

Region I

March 1975

ATTENTION

AS NOTED IN THE NTIS ANNOUNCEMENT, PORTIONS OF THIS REPORT ARE NOT LEGIBLE. HOWEVER, IT IS THE BEST REPRODUCTION AVAILABLE FROM THE COPY SENT TO NTIS.

FOREWORD

Transitions in water quality within individual water bodies have been recorded in geologic time for millions of years. However, these transitions have been the result of natural activities such as: climatic changes, tectonic movement, erosion, glacial movements, transgressive and regressive sequences of the seas, to name just a few. The recorded transitions have taken thousands of years in most cases. Man's activities within the last 2000 years has accelerated changes in water quality. His impact on the water bodies has become progressively more severe with his increasing population and industrialization. Under his present technological development, man has the ability to alter in seconds, what nature has taken eons to establish. In view of this fact, attempts have been made to encourage practices which can co-exist with the environment rather than inducing irreparable damages to it.

In order to exist harmoniously with the environment man has begun to realize the importance of understanding the mechanisms governing his environment and the importance of determining his impacts upon the environment. It was in this light that requests for additional information established the Connecticut River Supplemental Study.

It was felt that additional information on non-structural methods of flood control and environmental concerns was needed in order to establish the most comprehensive and compatible flood management program for the Connecticut River Basin.

Based on the information available, the Environmental Protection Agency was given the task of determining the degree to which various water quality parameters are affected by streamflow variations based on high and low flow conditions. The Agency was also to determine the amount of nutrients, sediments, and silts lost to the basin. This information was to be derived from data collected by EPA's Storet System, the United States Geological Survey, the Corps of Engineers dredging records, and individual state, local, and private sources. EPA was directed to present a sketch of factors primarily responsible for basin water quality and to forecast changes in these affecting factors and future water quality. EPA was also requested to present a detailed account on the effects of impoundments on water quality and to include with this a bibliography dealing with the effects of impoundments on water quality. Finally, EPA was requested to perform a water quality reconnaissance on the six tributaries that were being investigated by the Bureau of Sport Fisheries and Wildlife.

Although some of these tasks were not explicitly stated in the Supplemental Flood Management Study, Plan of Study, July 1, 1973, they were requested and implicitly required as the plan of study was formulated.

SUMMARY

AN ENVIRONMENTAL SKETCH OF FACTORS PRIMARILY RESPONSIBLE FOR BASIN WATER QUALITY

Water quality in the basin's natural condition was generally excellent. The activities of man have caused very serious local deterioration by discharging into the stream systems municipal and industrial wastes, chemical pollutants from industry and agriculture, sediment from agricultural and construction activities, heat from industry and power production and miscellaneous trash and refuse. However, present conditions indicate that the water quality, on the whole, is generally suitable for bathing, and recreational purposes, for public water supply with treatment, and for good aesthetic value. It is acceptable for many kinds of fish and wildlife and is suitable for agricultural and industrial uses. However, as stated, there are localized areas where water quality is seriously degraded. These degraded stretches of river are in the vicinity of urbanized areas which have inadequate or raw waste treatment or have combined sewer overflows as a part of their sewerage systems. The water quality in these areas is unsafe for human consumption (unless adequately treated) or body contact sports. Also, in these areas the water quality is generally such as to preclude the area to commercial harvesting of shellfish. The Federal Water Pollution Control Act Amendments of 1972, with more stringent treatment requirements should upgrade the water quality.

The water quality standards previously adopted by the states covering interstate waters have been extended to include all intrastate waters. These standards have been revised by the states and approved by both the states and the Federal Government.

STREAM FLOW AND ITS EFFECT ON WATER QUALITY

In order to determine the degree to which various water quality parameters are affected by stream flow variations, attempts were made to correlate water quality parameters with a series of flow regimes during the high flow period of March through May and during the low flow period of July through September at the National Network Monitoring Stations at Enfield, Connecticut; Northfield, Massachusetts; and Wilder, Vermont. The correlations indicated that, generally, 10% to 25% of the parameter variation can be attributed to flow. Thus the significant relations were weak and the correlations were mild. This indicates that the changes in water quality caused by flow variation are slight and that most of the variation in the parameters measured must be due to other factors such as effluent discharges, runoff, surrounding environments, use, and experimental error.

Of the 12 parameters examined, only ph, alkalinity and hardness exhibited similar trends at most stations. pH showed that there was little or no correlation between its value and flow, while alkalinity and hardness showed that an inverse relation existed between their concentrations and flow.

The quality of the data used in many cases was questionable. This is due to the numerous sources submitting data to Storet, poor sampling techniques, and experimental error. However, with the new program initiated by the States, the input into STORET is improving.

NUTRIENT LOSSES TO THE BASIN

Using the same Storet file indicated in section 1.0 attempts were made to determine the nutrient losses to the basin. Unfortunately, the Wilder Station was deficient in nutrient data. Nutrient loads in the form of phosphates and ammonia-nitrogen were determined at the Northfield and Enfield Stations for an average high and low flow.

The daily nutrient loads passing the Northfield Station range between 1,300-8,000 lbs/day for ammonia-nitrogen and 9,000-13,000 lbs/day for phosphates. The daily nutrient loads passing the Enfield Station range between 13,000-33,000 lbs/day for ammonia-nitrogen and 11,000-30,000 lbs/day for phosphates. The loads measured at each station show the net cumulative load acquired from the drainage area above the sampling station. Thus the load carried at Enfield reflects partially the load carried at Northfield.

The apparent anomaly indicated between the phosphate and ammonia-nitrogen load ratios exhibited at the two stations is probably a result of the individual sampling locations. The high levels of ammonia-nitrogen registered at Enfield are caused by the tremendous load of ammonia-nitrogen discharged into the river in the Springfield Metropolitan area just above Enfield. There is only a small discharge of ammonia-nitrogen to the river above Northfield.

The estimated nutrient loads carried by the Connecticut River do not account for those nutrients removed from the stream by oxidation, utilization or resuspension and, hence, as such are probably conservative. The nutrients measured are taken from samples which actually contain the net concentrations carried at the Northfield and Enfield Stations.

By measuring the amount of effluent being discharged from the municipal facilities and using a conversion factor for nitrogen and phosphorus, an estimate indicating the amount of nutrients which could be removed by expanding existing facilities to tertiary treatment is calculated. The calculations represent an average value for the nutrients being discharged in domestic wastes from municipal facilities in the basin.

A factor of 7-10 mg/l of phosphorus and 15-35 mg/l of nitrogen is used as the concentrations of these nutrients in domestic waste waters. The amount of the nutrients capable of being removed from the basin above Northfield is calculated to be 1,631 - 3,805 lbs/day of nitrogen and 761 - 1,087 lbs/day of phosphorus. Between Northfield and Enfield the amount of nitrogen capable of being removed is 8,236 - 19,218 lbs/day and 3,844 - 5,491 lbs/day of phosphorus. These figures illustrate the need for advanced waste treatment especially in the urbanized areas in the lower portions of the basin.

ESTIMATED SILT LOSSES TO THE CONNECTICUT RIVER BASIN

Data accumulated by the U.S. Geological Survey was used to estimate the silt loads lost to the Connecticut River. The data indicated that the major sediment loads and flows occurred during the winter and spring flows.

The flows and sediment loads in the winter and spring show the least correlation due to the unstable flow conditions that exist in the basin during these months. It is in the more stable flow regimes of the summer and fall that the generally higher degrees of correlation occur.

Based on the assumption that the erosion characteristics of the basin are typified in the tributaries sampled, estimates on the amount of sediment load carried by the Connecticut River were attempted. The Connecticut River is estimated to carry approximately .75 million to 5 million pounds of sediment each day. This may not be a very large amount when the size of the drainage area and the amount of resuspended existing sediments are considered. Nonetheless, the deposition of eroded sediments has a cumulative effect on the stream bed until the sediments are moved out by high flows.

The Corps of Engineers' dredging records and other reports indicate that, although a portion of the sediment at the mouth of the river is deposited during alongshore movement of sediment, above the mouth much of the deposition comes from excavated soil moving back into the channel from nearby spoil areas. The sediment derived from erosion sources within the Basin is a minor source of the material deposited in the navigation channel. Other reports also indicate that erosion on the whole is minimal.

Surveys indicate that if the farmers relied solely on sediment renewal rather than fertilizers, their crop production would be only marginal.

Even though evidence indicates a relatively minor amount of siltation occurs in the Connecticut River as a whole, there are local instances where induced sedimentation has been severe enough to cause serious economic losses to local residences. The Gale River has had extreme sediment buildups during the last ten years. Evidence indicates that nearby long-term construction of I-93 has been a major source of this sediment buildup. Frequent fluctuations in storage pool elevations at the hydroelectric dams has also been linked with stream bank erosion problems. In most instances, areas of large scale sediment buildup can usually be traced to improper land management, development or construction practices.

CHANGES IN WATER QUALITY AS A RESULT OF IMPOUNDMENT

Impoundments placed on a stream will alter the physical conditions within a stream. The natural changes, plus changes induced by man's activities around the impoundment can cause large scale changes in water quality. This can pose serious threats to future quality and life in the river or impoundment. For this reason there are both direct and indirect ramifications which must be considered before accepting a structural method of flood control.

When using an impoundment for flood control, concern should be emphasized on the effects of thermal stratification, nutrient influx, the settling basin created by the impoundments, downstream releases, the impoundment's influence on groundwater, and development around the impoundment. If an impoundment is to be used for flood control, then ways to maintain water and environmental quality are available and should be implemented as part of the program, the most basic considerations being the limitation of developments around the impoundment, the enforcement of proper waste treatment both upstream and in close proximity to the structure and its impoundment, and downstream releases of impounded water.

LAND USE FUNCTIONS IN WATER QUALITY MANAGEMENT

Since water quality is so dependent upon land use, it is becoming more rapidly accepted that controlled land use is an essential part of water quality management.

The concept of reserving land for functional open space is currently practiced. An important practice of reserving a strip of land in the floodplain of a river is now being considered in many areas. The maintenance of this buffer strip alongside all streams applies to forest, agriculture, and urban land alike. This well vegetated strip would effectively reduce the influx of phosphorus, pesticides, and suspended particulate matter. It would stabilize river banks, enhance the appearance of water bodies and offer some area for outdoor recreation such as hiking, camping and hunting. This practice prevents excessive flood plain enchroachment and leads to reduced flood damages.

WATER QUALITY RECONNAISSANCE OF SIX SELECTED TRIBUTARIES

Six watersheds were selected so as to be coincident with the watersheds analyzed by the Bureau of Sport Fisheries and Wildlife. They are the Deerfield and Westfield Rivers in Massachusetts, the Ammonoosuc River in New Hampshire, the White and Passumpsic Rivers in Vermont and Whetstone Brook in Vermont. On each watershed a water quality reconnaissance was performed based on the data available.

Westfield River

The dissolved oxygen was found to be above 5 mg/l. Alkalinity was found to be higher due to discharges around West Springfield and the influence of the Westfield Little River which was found to have higher alkalinity concentrations. The suspended solids and BOD peaks are higher around industrial and urbanized areas indicating the impact of man's activities upon the stream. In many classified B waters, standards are violated with respect to coliform numbers, especially around Westfield, Agawam and West Springfield.

Deerfield River

Dissolved oxygen concentrations were above 5.0 mg/l at all points sampled. However, coliform standards for class B waters were violated in all instances except at the last two sampling stations about 33 miles above the confluence with the Connecticut River.

The North and Green Rivers are subject to stress as is indicated by the sampled values. The Green River recorded the highest suspended solids concentration for the entire system and the lowest dissolved oxygen concentration of less than 1 mg/l. The North River recorded the highest pH value for the entire basin area sampled. The data indicated that the waste load carried by the Green River was felt in the Deerfield after the confluence of the two rivers.

There are four sections of the Deerfield Basin that are classified below B:

1. the lower portions of the Deerfield after confluence of the Green River,
2. the lower portions of the Green River,
3. the lower portions of the North River, and
4. a section of the Deerfield near Monroe.

These lower classifications are due to conditions generated by nearby discharges.

Whetstone Brook

The Whetstone offers no significant flood contribution to the Connecticut River, but due to its flashflood nature, it poses special problems to the Town of Brattleboro. The dissolved oxygen concentration is greater than 7.0 mg/1, throughout. Whetstone Brook illustrates the typical effect of urban development along a stream. All the parameters measured except coliforms indicated low concentrations until the stream passed through the urbanized Brattleboro area. The coliform counts violated the Class B standards at all stations sampled. However, below the populated centers, the concentrations were significantly higher. The high MPN coliform counts found in the sampled stream portions are thought to be caused by animal wastes or seepage from the mobile homes and houses located along the brook. Whetstone Brook is presently classified "B" except Pleasant Valley Reservoir which is classified "A".

White River

Presently classified "B", the White River had a dissolved oxygen concentration greater than 7.0 mg/1. The BOD profile is low, but peaks generally coincide with the DO profile depressions. Short narrow BOD peaks indicate a high rate of reaeration.

The BOD profile and the coliform profile indicate wastes are being discharged from West Hartford, Bethel, Royalton, South Royalton, and Granville.

Alkalinity indicates a significant anomaly. Due to the geologic terrain over which the three Branches flow, the alkalinity is significantly higher. Due to the Branches' contribution, the alkalinity in the mainstem after their confluence is significantly higher than that measured in the mainstem before the confluence of the Third Branch at Bethel.

Again coliform counts around population centers are high and in these areas the number of coliforms violate "C" state standards.

Ammonoosuc River

The Ammonoosuc River is classified "B" with some upper portions of its tributaries being classified "A". Almost all stations passed on the class "B" requirements for dissolved oxygen. The station reporting the lowest DO saturation of less than 75% was still at 70% saturation.

Coliform counts exceeded "B" standards at all but one upstream station. The parameters sampled showed the effects of discharges from the population centers of Bethlehem, Lisbon, Bath Littleton, and some resort hotels in the upper portion of the basin.

The data available was old and limited to only a few pertinent parameters.

Passumpsic River

The Passumpsic River Basin is presently classified "B". The dissolved oxygen at all points measured was greater than 7.0 mg/l except at one station where 6.7 mg/l was recorded. Hence, the stream will support natural trout populations. The BOD profile, the MPN coliform profile, and the depressions in the DO profile indicate the effects of discharges from S. Johnsbury, Lyndon, Lyndonville and the Sleepers River.

In no case did the stations sampled meet the "B" standards for coliform MPN counts.

It is recognized that through compliance with the 1972 Amendments to the Federal Water Pollution Control Act and installation of the proposed treatment plants, many of the standards violations will be eliminated. Also, it is recognized that a more updated sampling program would enhance some of the water quality profiles discussed.

TABLE OF CONTENTS

Page

FOREWARD i

SUMMARY ii

TABLE OF CONTENTS ix

LIST OF TABLES, FIGURES AND MAPS xi

INTRODUCTION 1

1.0 AN ENVIRONMENTAL SKETCH OF FACTORS PRIMARILY RESPONSIBLE FOR BASIN WATER QUALITY.................. 3
  1.1 General.. 3
  1.2 Existing Uses.................................. 5
  1.3 Existing Types of Discharges................... 8
  1.4 Standards and Existing Water Quality........... 15

2.0 STREAM FLOW AND ITS EFFECT ON WATER QUALITY.......... 23

3.0 NUTRIENT LOSSES TO THE BASIN......................... 28

4.0 ESTIMATED SILT LOSSES TO THE CONNECTICUT RIVER BASIN.............................. 36

5.0 CHANGES IN WATER QUALITY AS A RESULT OF IMPOUNDMENT.. 45
  5.1 Introduction................................... 45
  5.2 Thermal stratification......................... 45
  5.3 Settling basin effect.......................... 47
  5.4 Eutrophication................................. 47
  5.5 Light penetration and turbidity removal........ 48
  5.6 Oxygen production and demand................... 49
  5.7 Carbonate equilibrium.......................... 51
  5.8 Iron and Manganese............................. 51
  5.9 Artificial destratification of impoundments.... 52
  5.10 Thermal pollution............................. 52
  5.11 Influence of impoundment releases on downstream water quality....................... 53
  5.12 Effects on groundwater........................ 54
  5.13 Watershed development......................... 55
  5.14 Remarks....................................... 56
  5.15 Bibliography dealing with the effects of impoundments on water quality.................. 57

6.0 Land use functions in water quality management....... 72

TABLE OF CONTENTS

Page

7.0 WATER QUALITY RECONNAISSANCE OF SIX SELECTED TRIBUTARIES.......................... 75
7.1 The Westfield River Basin.................... 80
7.2 The Deerfield River Basin.................... 89
7.3 The Whetstone Brook Basin.................... 101
7.4 The White River Basin........................ 109
7.5 The Ammonoosuc River Basin................... 118
7.6 The Passumpsic River Basin................... 126

GLOSSARY... 137

APPENDICIES

Preface: Discussion of Flow Regressions.......... A-B-1
Appendix A: Linear Regressions Comparing Stream Flow to Concentration for Various Parameters.......................... A-1
Appendix B: Linear Regressions Comparing Stream Flow to Load for Various Parameters.. B-1

LIST OF TABLES, FIGURES AND MAPS

		Page
Figure 1	- Stresses Which Influence Water Quality.........	2
Map 1.1	- Connecticut River Delineated Basin Map.........	9
Table 1.1	- Water Quality Standards Revisions Adopted by the Connecticut River Basin States in the Period November - December 1973.............	17
Map 1.2	- Connecticut River Water Quality Classification Map..........................	19
Table 1.2	- General Use Descriptions for Various Water Quality Classifications Found in the Connecticut River Basin.....................	22
Table 2.1	- Relationships Determined by Linear Regression Analysis for Concentrations..................	26
Table 3.1	- Comparison of Various Plant Nutrients With Respect to Controllability by Man and Growth Controlling in Lakes................	29
Table 3.2	- Nutrient Losses Estimated from Storet Data Taken During the High and Low Flow Periods..	31
Table 3.3	- Amount of Nutrients Capable of Being Removed by Upgrading Existing Municipal Facilities to Tertiary Treatment......................	32
Figure 3.1	- Phosphorus and Nitrogen Distribution in an Agrarian Economy...........................	35
Figure 3.2	- Phosphorus and Nitrogen Distribution in a Simple Urban Economy.......................	35
Figure 3.3	- Phosphorus and Nitrogen Distribution in a Complex Urban Economy......................	35
Table 4.1	- Suspended Sediment Loads at Various Points and Various Time Periods in the Connecticut River Basin Measured during 1965 - 1973.....	37
Table 4.2	- Sediment Loads at Various Points in the Basin.	39
Table 4.3	- Army Corps of Engineers Dredging Records in the Connecticut River Basin Estuary.............	41

Page

Map 7.1 - Westfield River Basin........................ 81
Figure 7.1a Dissolved Oxygen............... 84
Figure 7.1b Temperature.................... 85
Figure 7.1c Alkalinity..................... 86
Figure 7.1d Suspended Solids............... 86
Figure 7.1e BOD_5........................... 87
Figure 7.1f Coliforms...................... 88

Map 7.2 - Deerfield River Basin........................ 91
Figure 7.2a Dissolved Oxygen............... 93
Figure 7.2b Coliforms...................... 94
Figure 7.2c BOD_5........................... 95
Figure 7.2d Alkalinity..................... 96
Figure 7.2e Total Suspended Solids......... 97
Figure 7.2f Temperature.................... 98

Map 7.3 - Whetstone Brook Basin........................ 99
Figure 7.3a Dissolved Oxygen............... 102
Figure 7.3 BOD............................. 103
Figure 7.3c Total Solids................... 104
Figure 7.3d Suspended Solids............... 105
Figure 7.3e Temperature.................... 106
Figure 7.3f MPN Coliforms.................. 107

Map 7.4 - White River Basin............................ 111
Figure 7.4a Dissolved Oxygen............... 113
Figure 7.4b BOD............................ 114
Figure 7.4c Temperature.................... 115
Figure 7.4d Coliforms...................... 116
Table 7.4-1 Data on Three Branches of the White River............................ 117

Map 7.5 - Ammonoosuc River Basin....................... 119
Figure 7.5a Dissolved Oxygen............ 122
Figure 7.5b Temperature................. 123
Figure 7.5c pH.......................... 124
Figure 7.5d Coliforms................... 125

Map 7.6 - Passumpsic River Basin....................... 127
Figure 7.6a Dissolved Oxygen............ 129
Figure 7.6b BOD......................... 130
Figure 7.6c Total Solids................ 131
Figure 7.6d Suspended Solids............ 132
Figure 7.6e Alkalinity.................. 133
Figure 7.6f Temperature................. 134
Figure 7.6g Coliforms................... 135

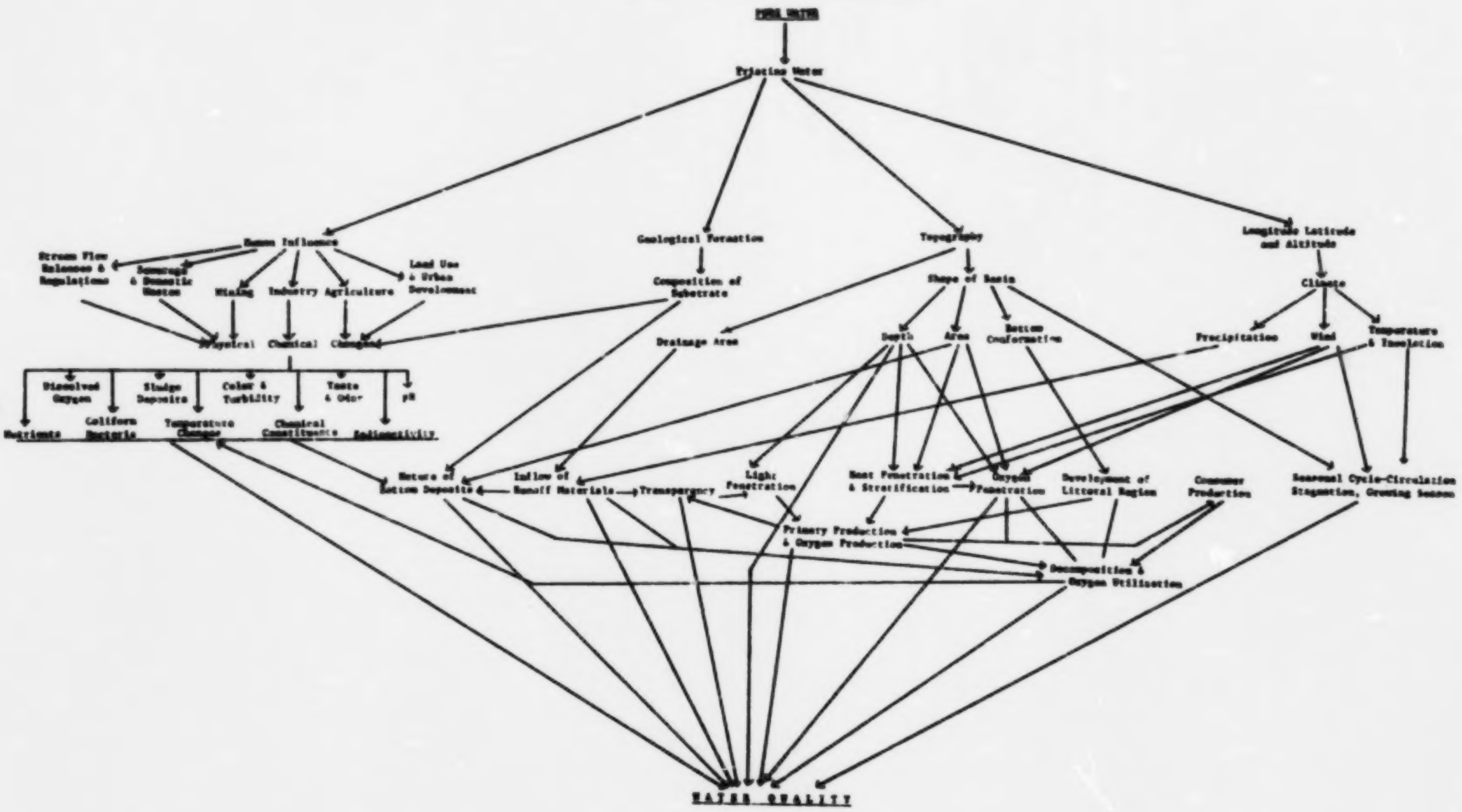
INTRODUCTION

Pure water composed of hydrogen and oxygen is subject to the stresses and influences from the surrounding environments as is shown in Figure 1. However, the surrounding environments each have many complexities and interrelationships associated with them and may produce different modifications on water quality under similar conditions. For example, during periods of high flow, pollutants are usually diluted, improving water quality in one respect, while combined sewer overflows, sewage treatment plant "by-passes" and increased erosion and runoff also associated with high flow periods are responsible for water quality degradation.

In order to have any effective water quality management, it is necessary that these interrelationships be understood and that all the ramifications involved with water use be designed and implemented so as to achieve a desired water quality.

In establishing a flood management program which involves both structural and non-structural features, it is necessary to consider what roles these features will play in affecting water quality. Accordingly, the Environmental Protection Agency's role in Phase I of the Connecticut River Supplemental Study will be to briefly examine those factors primarily responsible for basin water quality; examine what effects flows have on water quality; estimate the amount of nutrients and sediment carried in the Connecticut River Basin; investigate the possible effects impoundments may induce both directly and indirectly on water quality; examine the effects land use has on water quality and perform a water quality reconnaissance on selected tributaries in the Connecticut River Basin.

Figure 1 - Stresses Which Influence Water Quality


PURE WATER
Existing Water
Human Influence
Geological Formation
Topography
Longitude Latitude and Altitude
Stream Flow Balances & Regulations
Sewerage & Domestic Wastes
Mining
Industry
Agriculture
Land Use & Urban Development
Composition of Substrate
Shape of Basin
Climate
Physical Chemical Changes
Drainage Area
Depth
Area
Bottom Conformation
Precipitation
Wind
Temperature & Insolation
Dissolved Oxygen
Sludge Deposits
Color & Turbidity
Taste & Odor
pH
Nutrients
Coliform Bacteria
Temperature Changes
Chemical Constituents
Radioactivity
Nature of Bottom Deposits
Inflow of Runoff Materials
Transparency
Light Penetration
Heat Penetration & Stratification
Oxygen Penetration
Development of Littoral Region
Consumer Production
Seasonal Cycle-Circulation Stagnation, Growing Season
Primary Production & Oxygen Production
Decomposition & Oxygen Utilization
WATER QUALITY

1.0 AN ENVIRONMENTAL SKETCH OF FACTORS PRIMARILY RESPONSIBLE FOR BASIN WATER QUALITY

1.1 General

The Connecticut River Basin, an area of 11,136 square miles, extending 404 miles from Canada to Long Island Sound, is embraced by four states. Thirteen percent is in Connecticut, with 25 percent in Massachusetts, 27 percent in New Hampshire and 25 percent in Vermont. Excluded from this study are 114 square miles in Canada. The main river separates New Hampshire and Vermont (west bank) and cuts through the west-central sections of Massachusetts and Connecticut. With its system of 33 tributaries, the Connecticut River drains 41 percent of Vermont, 33 percent of Massachusetts and New Hampshire and 29 percent of Connecticut. Eighteen tributary basins range in size from 150 to 700 square miles. The main tributaries, White, Deerfield, Westfield, Farmington and Chicopee Rivers have drainage areas in excess of 500 square miles.

Hilly uplands prevail throughout much of the basin. Important ranges of hills and mountains are the Berkshire and Green Mountains forming the western margins of its middle and lower portions and the White Mountains in its upper easterly portion. Extensive lowlands are confined to the flood plains of Massachusetts and Connecticut.

Total yearly precipitation averages about 43 inches of water with a range of 35 to 60 inches. Runoff, reflecting large snowmelt in the spring, represents a little more than 50 percent of annual precipitation. The average flow of the Connecticut River in the lower basin, as measured just below the Massachusetts-Connecticut State Line is 15,900 cubic feet per second. Four tributary streams have mean flows of 1,000 cfs or more. These are the White River, with its confluence near the upper limit of the middle part of the basin, and the Deerfield, Chicopee and Farmington Rivers with confluences in the lower basin. Frost-free periods range from 180 days near Long Island Sound to 100 days in the upper basin.

The Connecticut River Basin is underlain by crystalline bedrock, which varies from metamphorphic and igneous rocks, composed of gneiss, schist, phyllite, slate, and quartzite, to sedimentary rocks with structures which generally dip 10 to 30 degrees to the east. The metamorphic rocks have been intruded by igneous rocks including granite, pegmatite, diorite, gabbro and diabase. Bedrock in the igneous and metamorphic regions has a complex structure characterized by intense folding and faulting. The sedimentary rocks are interbedded with basalt, which is of volcanic origin. The more resistant basalt forms so-called trap ridges.

Prior to continental glaciation, weathering throughout the basin had formed a thick cover of residual soil over bedrock similar to that further south in the Piedmont Plateau and Blue Ridge Mountains. As the ice sheet formed and advanced, it removed first the loose residual soil and then removed blocks of solid rock. Both soil and rock were transported and deposited by ice as glacial till. Glacial streams and lakes which developed in association with the glacier were the sites of water-laid deposits of sediment.

Topography is controlled primarily by underlying bedrock, rather than by surficial materials. Glacial till covers the greater portion of the land area of the basin with deposits of varying thickness. Over most of the basin till includes rock fragments similar to underlying or nearby bedrock indicating it was not transported far from its source. The till was deposited directly from the ice mass and is not sorted but includes material ranging from plastic fines to boulders.

In contrast to the glacial till are the stratified deposits transported and deposited in glacial streams and lakes. In general, these are thicker than till deposits and may overlie either bedrock or till. These deposits occur along the main and tributary valleys. They may occur as terraces, winding ridges, or highly irregular topography. These sediments are well sorted, consisting of gravels, sands, silts and clays. Due to the geologic and pedologic conditions primarily created by the glacial activity in the basin, water quality in the basins natural environment was generally excellent.

Basin population in 1960 was 1,680,000 or about 20 percent of the total population in the four states. Two major metropolitan areas, Springfield and Hartford, in the lower basin account for 48 percent of the basin population. The total basin population is 72 percent urban. Towns with 10,000 or more people are found outside the metropolitan areas in the lower basin and to a more limited extent in its middle portion, but they are absent in the upper basin.

The economy of the basin relies to a large extent on the industrial activity which is located along the mainstem and major tributaries. In general, industrial activity is more concentrated in the southern half of the basin where the chemical, metal fabricating and electronic industries are significant contributors to the economy. Agriculture, textiles, the paper industry and recreational developments are also significant contributors to the economy. For the most part, these activities are more concentrated in the northern half of the basin and in areas of the southern basin removed from the main stem or major tributaries.

Since the original water quality in the basin was excellent and man's activities have been responsible for serious deteriorations in this condition in some areas, the quality of the Basin's water depends primarily upon existing demands, both point and non-point source discharges to the streams and the waterways ability to assimilate the waste load placed upon them.

1.2 Existing Uses

The use of water for any purpose requires that both water of adequate quantity and adequate quality be available for the particular purpose. For some uses such as municipal water supply, quality needs are stringent and special treatment facilities or strict watershed control measures are required. At the other extreme, uses such as navigation, which requires a lesser quality, are nonetheless affected by such things as debris, scums, aquatic organisms, clarity and sediment load. A water resource development plan must therefore consider what the quality requirements are for each proposed water use.

Many areas of the Connecticut River Basin now suffer from a degraded water quality which precludes or impairs the use of the waters for many ligitimate demands. On the mainstem Connecticut River, the water quality below the Upper Ammonoosuc River and again in the vicinity of Springfield, Massachusetts is seriously degraded for a significant distance. Water quality on portions of the tributaries: Ashuelot, Mascoma, Sugar, Black, Upper Ammonoosuc, Millers, Chicopee, Deerfield and Farmington Rivers and other smaller streams is similarly degraded. In general, present water quality varies not only among the different tributaries but within sections of individual tributaries and the mainstem itself.

The quality of the basin's water resources represents a valuable asset to the future growth of the basin. Future demands much greater than present demands are expected to occur throughout the full spectrum of water uses.

The varied character of the study area, the high demands of a densely populated region for useful water quality levels, and the heavy pollution loads associated with urban and industrial developments lead to a wide range of water quality needs. These include the need to protect good recreation waters for and from the recreator, the need to provide a healthful and aesthetic aquatic setting, the need to meet the water supply requirements of a growing population and economy, and the need to treat and dispose of large quantities of waste without violating the environment. The diverse demands impose a serious challenge to the sound management and use of water and heighten the importance of a well integrated water resource plan.

The basin's total water supply demand amounts to an estimated 505 million gallons per day (mgd). This demand comes from the basin's municipal water systems and from its industrial complex exclusive of electric utilities and mineral industries. As population and industrialization in the basin increase, water supply demands will simultaneously increase. By 2020 the water supply demands of municipalities and industries are expected to more than double the present demands of 505 mgd. Certain areas of the basin can be expected to experience a much greater rate of demand increase than the basin viewed as a whole due to the uneven distribution of the population.

Municipal water supplies provide for domestic use, industrial use, industrial processing and cooling uses, commercial uses, public use and water lost through leakage, although all of these demands may not be present in any given water system. The use of water for all of these purposes is generally expressed on an average per capita basis as gallons per capita per day or gpcd. On a national level, estimates have indicated that the 1960 usage of municipal water averaged about 151 gpcd and ranged from about 100 to 341 gpcd. Usage of municipal water in New England and the Connecticut River Basin averages about 117 and 124 gpcd, respectively.

In addition to water supply demands within the basin, the Connecticut River is included in the comprehensive plan to meet the water supply needs of the Metropolitan District Commission service area. The Massachusetts Legislature has authorized diversion of surplus Connecticut River water into Quabbin Reservoir by the Northfield Mountain pumped storage project to meet these needs. The Commission notes that Quabbin Reservoir, Massachusetts' largest water supply serving nearly half of the State's population, has not recovered from the drought of the middle and later 1960's. It has decreased more than five percent -- or four-and-one-half feet -- in the past year and has exceeded its maximum safe yield continuously for several years. Transfer of excess flows from the Connecticut River Basin is considered an essential short-term solution.

Diversion of surplus water from the Basin is recommended subject to recognition of riparian rights, specifically, the right of return of these waters when needed for water supply or flow augmentation within the Basin.

The Commission recommends diversion of water from the Millers River watershed into Quabbin Reservoir by modification of the existing Tully Reservoir to include storage for flood skimming. Approval of Tully and any diversions at Northfield Mountain above amounts presently authorized by law* are conditioned on:

---

* The amount of water that may be diverted at Northfield Mountain is limited by Massachusetts law over a three consecutive year period to 375 million mgd for each day that river flow exceeds 17,000 cfs at Montaque City. Diversion is prohibited by law on any day when flow is less than 17,000 cfs at Montaque City. Chapter 766, Act of 1970, M.G.L.

creation of a regional mechanism for allocating water in which downstream States have a voice. In the event that the creation of such a mechanism proves unfeasible, it is recommended that its functions be performed by existing institutions with appropriate regional resource management capabilities;

prior measurement of the impacts -- environmental, social, public health, economic and other -- used in determining "excess flows";

prior determination of the location and available yield of alternative groundwater sources in the Basin and on development of adequate measures for their protection, in coordination with environmental and flood management studies conducted as part of the supplemental study program.

The Commission recommends that all proposed diversions of Connecticut River water below the newly constructed nuclear power plant at Vernon, Vermont, including Northfield Mountain, be conditioned on satisfactory completion of environmental impact evaluations of the power plant. It is recommended that these evaluations include careful investigation of the possibility of radioactive contamination of Connecticut River water and its implication for the diversion of Connecticut River water in Quabbin Reservoir. It is further recommended that proposed diversions be conditioned on adequate measures to prevent radioactive contamination of diverted water, including water quality monitoring.

Finally, the effects of this flood skimming should be investigated thoroughly with respect to water quality conditions both presently and in the future since the high waters do serve an important role of flushing contaminants from the stream and stream sediments. The elimination of high flows downstream may induce adverse effects on water quality by allowing contaminant buildup.

Required water treatment to the basin's municipal supplies varies from very little (i.e. disinfection) in the northern less populous regions to softening, water stabilization, aeration, sedimentation, filtration, and taste and odor control in the more populous regions. Data indicates that areas most dependent on surface supply sources rather than groundwater sources require greater treatment.

Most of the river system's water use can be classified as industrial since very little mainstem or tributary water is used for consumption. The industrial activities within the basin are widely diversified. In the comprehensive report on the Connecticut River Basin Appendix D - Water Supply and Water Quality, the industrial activities within the basin were delineated into 6 regions and the present and probable future industrial components of each region were discussed.

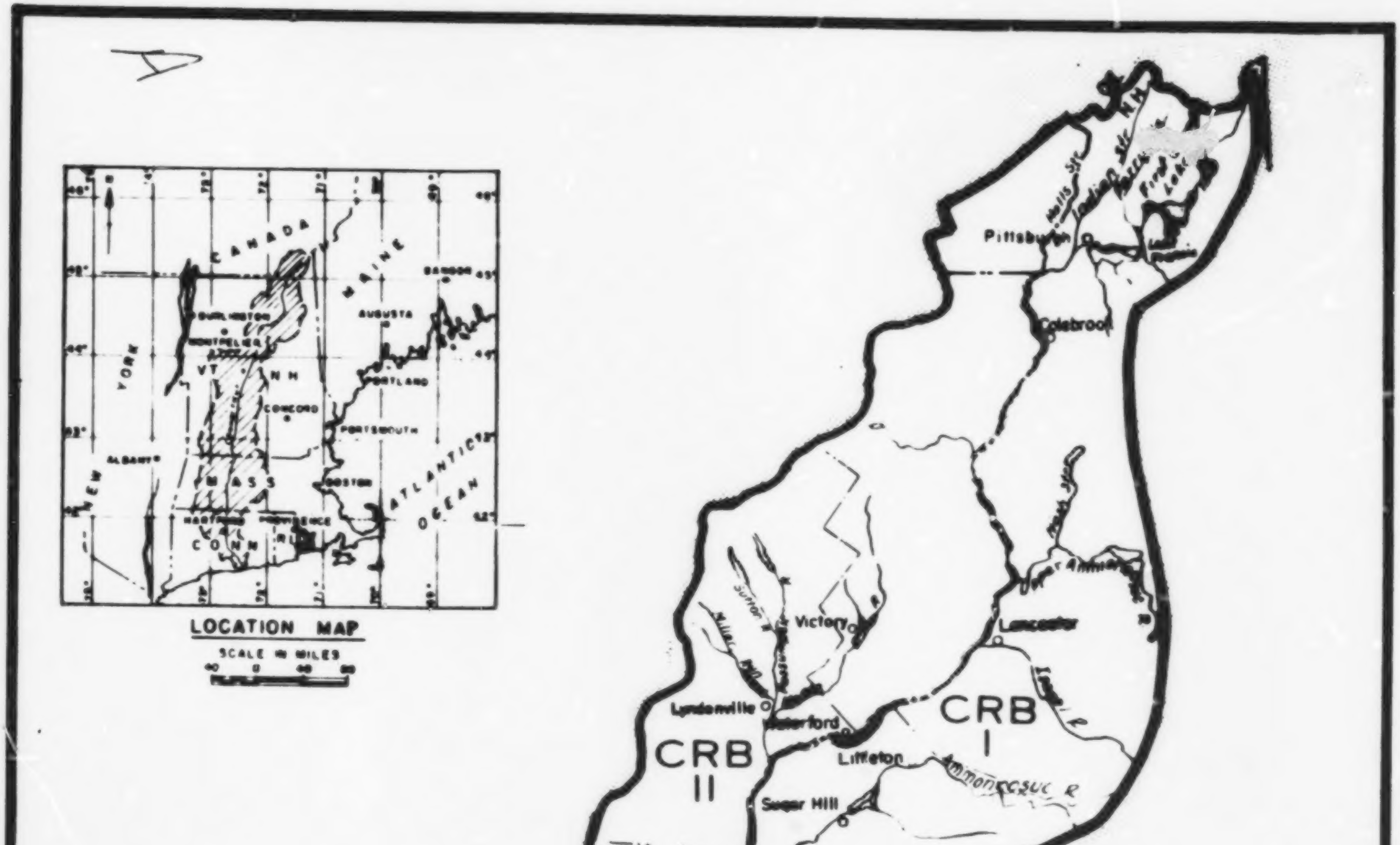
Map 1. 1 indicates the 6 regions listed as CRB I-CRB VI. CRB I is dominated by paper and textile industries. CRB II is dominated by manufacturing in the lumber, wood, paper and machinery industries. Region CRB III is marked by the textile and leather manufacturing industries, with machinery and electrical machinery industries experiencing vigorous growth in this region recently. Non-electrical machinery has traditionally been Region IV's largest single manufacturing industry. Lumber and wood product industries have been declining, while growth in the non-electrical and electrical machinery industries has been increasing. CRB V is marked by the non-electrical machinery, paper and allied products, textiles, and fabricated metals industries. The most important manufacturing industries in CRB VI were in transportation equipment, non-electrical machinery, fabricated metal products and electrical machinery.

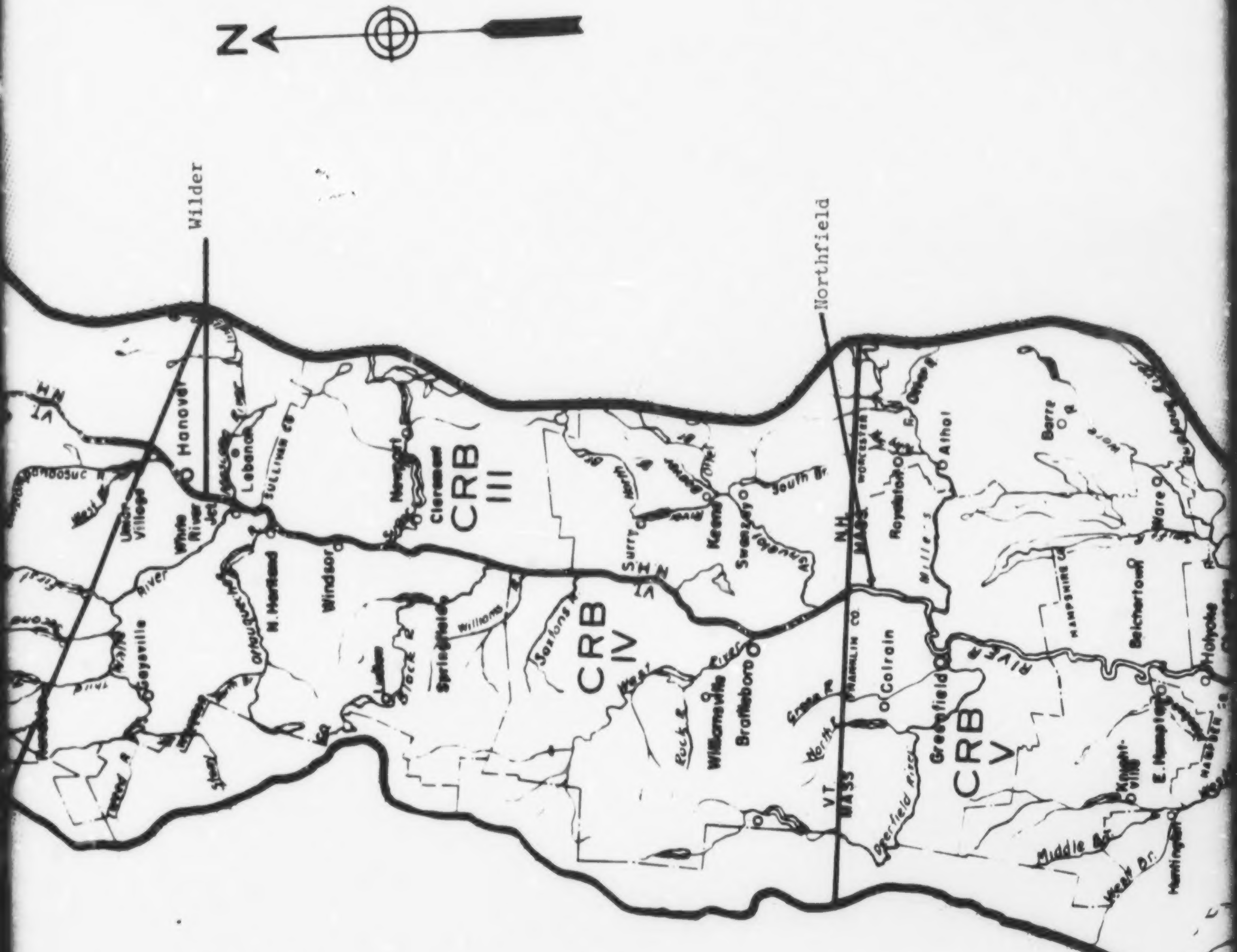
A final major water use in the basin is hydro power. The early development of hydroelectric power in the Connecticut River Basin was extremely important in the Basin's industrialization and urbanization. The entire river system may be considered to have had a certain potential for hydroelectric development which has been utilized step by step as the power loads increased and the projects became economically feasible. With the completion of the S.C. Moore Dam and Power Station in 1956, the last hydroelectric site, favorable under the present economy, was utilized. Further development of conventional hydro power at a cost competitive with the cost of equivalent power and energy from alternative sources, such as pumped storage and thermal electric plants, is unlikely.

Even though the Basin's municipal water supply for the most part is not taken from the Connecticut River or its tributaries, many of the basin's waste materials are discharged to its waterways. All of the above industries are associated with effluents which can place severe demands on a waterway's assimilative capacity.

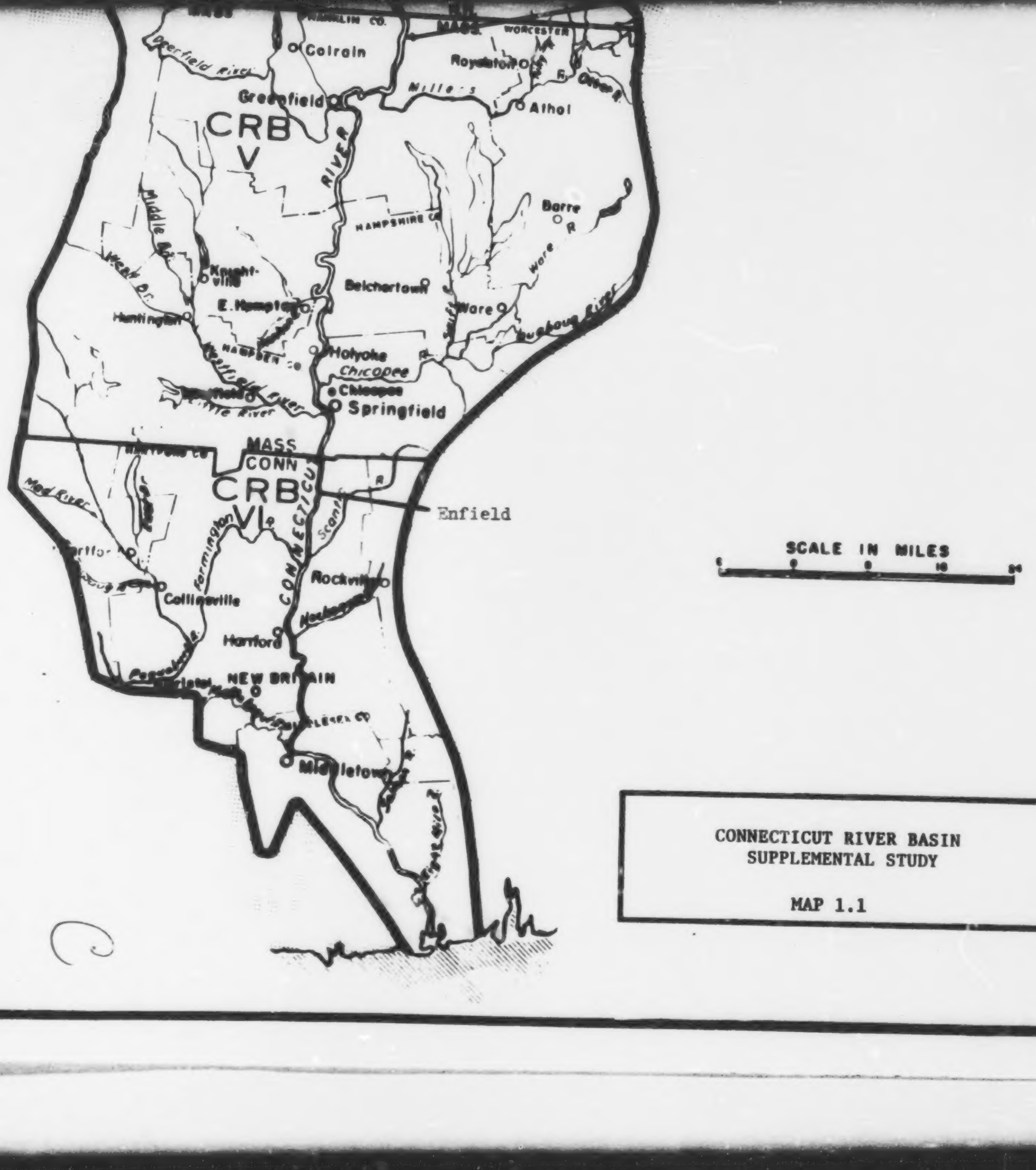
1.3 Existing Types of Discharges

The Connecticut River Basin like any river system is in balance with its surroundings. The river system has an assimilative capacity which can "sorb" and purify a certain volume of the waste material or waste load. In order to be in proper balance with nature the amount of purification capable by a stream is generally equal to the amount of waste material and nutrients that originate within the river system. Under natural pristine conditions a stream has no trouble handling the wastes it receives since it is highly unlikely that, under these conditions, all the basin's wastes would be in the river at the same time.


LOCATION MAP
SCALE IN MILES
40 0 40 80
CANADA
MAINE
BANGOR
AUGUSTA
BURLINGTON
MONTPELIER
VT
N H
YORK
NEW
CONCORD
PORTLAND
PORTSMOUTH
ALBANY
MASS
BOSTON
ATLANTIC
OCEAN
HARTFORD
PROVIDENCE
CONN
R.I.
CRB
I
CRB
II
Pittsburgh
Indian Str
Hallis Str
N.H.
First Lake
Colebrook
Lancaster
Victory
Lyndonville
Waterford
Littleton
Ammonoosuc R
Sugar Hill
Woodsville
Haverhill
Wells R
South
Corinth
Ompompanoosuc R
VT
N.H.
West R
Union Village
First Br
Second Br
Third
White
Gaysville
Ayers
Tweed R
Miller Run
Sutton R


N
Wilder
Northfield
CRB III
CRB IV
CRB V
Hanover
Lebanon
White River Jct.
Union Village
Gaysville
White River
Claremont
Newport
Sullivan Co.
Windsor
N. Hartland
Springfield
Williams
Black R.
Saxtons R.
Surry
Keene
Swanzey
Ashuelot
South Br.
VT
NH
MASS
West River
Williamsville
Brattleboro
Rock R.
Green R.
North R.
Colrain
Franklin Co.
Deerfield River
Greenfield
Worcester Co.
Royalston
Athol
Millers R.
Barre
Ware R.
Ware
Hampshire Co.
Belchertown
Holyoke
River
E. Hampton
Knightville
Middle Br.
West Br.
Huntington
Hampden Co.

B


MASS
FRANKLIN CO.
Colrain
MASS
WORCESTER
Royalston
R.
Otter R.
Miller's
Athol
Deerfield River
Greenfield
CRB
V
RIVER
Barre
R
HAMPSHIRE CO
Ware
Middle Br.
West Br.
Knightville
Belchertown
E. Hampton
Ware
Swift R.
Huntington
Quaboag River
HAMPDEN CO
Holyoke
R.
Westfield River
Chicopee
Chicopee
Little River
Springfield
MASS
HARTFORD CO
CONN
CRB
VIa
Mad River
R
Enfield
Farmington
Scantic
CONNECTICUT
Collinsville
Rockville
Hockanum
Hartford
Pequabuck R.
NEW BRITAIN
MIDDLESEX CO
Middletown
SCALE IN MILES
C

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY

MAP 1.1

However, man's activities in the basin have tended to upset the balance in nature by overloading the streams assimilative capacity with wastes and nutrients which originate outside the basin. The logic behind this is as follows. In the past, man's population was small and widely dispersed in an agrarian society. Nutrients and wastes in the agrarian society were also widely dispersed. The waste contribution to the streams and ground water was well below the assimilative capacities. With the advent of the Industrial Revolution; man migrated into cities and the population became more concentrated. The once widely dispersed population now became so concentrated that in the U.S. by 1965, it was estimated that 70% of the population lived on 2% of the land area. Due to the role water now played in man's life, it was important that urban centers be located on or near large bodies of water.

With the buildup in urban centers, it had become necessary for the farmers to produce more food. This food, a nutrient source for man, was for the most part shipped to the large population areas from outside the basin. With the development of the water closet and the combined sewer systems which were needed in the urban societies, man's wastes and associated nutrients were passed directly to the water systems.

The type of wastes discharged to the Connecticut River can be categorized into three classes - municipal, industrial, and agricultural. Industrial wastes are usually discharged directly through a pipe or conduit. These are called point source discharges, while agricultural wastes are usually introduced in runoff waters and as such constitute non-point sources of pollution. Municipal or domestic wastes can be either point or non-point sources of pollution. They are considered a point source when discharged through a sewer or treatment plant and a non-point source when the contamination results from improperly constructed or overloaded septic systems and poorly located spray irrigation sites. Runoff from urbanized areas constitutes another source of contamination. The existence of sewer systems determines whether the runoff material is from point or non-point sources. The shock loading of streams due to street runoff during storms has been shown in many areas to be a more serious source of pollutants than are municipal wastes.

The type of waste load dictates what the effects will be on water quality. Organic waste loads occurring in domestic sewerage and in some industrial discharges from factories and stock yards exert a high biological oxygen demand during stabilization, causing a depletion in the stream's oxygen supply. Industrial wastes which are primarily chemical in nature generally have a toxic effect on organisms and/or exert a chemical oxygen demand on streams causing again an oxygen depletion. In addition to oxygen demands and toxic substances, municipal and industrial pollution contains

Preceding page blank

nutrients necessary for eutrophication, principally nitrogen and phosphorus. The use of phosphate containing detergents has greatly expanded the problem of nutrient enrichment to municipal systems. The influx of nutrients causes increased algae production which leads to obnoxious algae blooms, taste and odor problems, eventual oxygen depletion, and overall aesthetic degradation of the surroundings. Debris and contaminants from open land areas, publicly used chemicals, air-deposited substances, ice control chemicals, and dirt and other contaminants washed from vehicles are among the sources of pollution in urban runoff water. The wastes generated in storm runoff usually contain solids, oxygen demands, nutrients, coliforms, pesticides and heavy metals.

Appendix D of the Comprehensive Study on the Connecticut River Basin contains an inventory of significant organic pollution discharges to the Connecticut River and its tributaries. The appendix gives projected values for the BOD_5 load by 1980 and 2020 based on 85% BOD removal through treatment plants. However, with enforcement of the 1972 Amendments to the Federal Water Pollution Control Act, which has as a goal, "the elimination of all discharge of pollutants into navigable waters by 1985", it is hoped that these BOD_5 projections will be obsolete.

Agricultural practices in the Basin are thought to be in a transitional stage. The Connecticut River is undergoing a steady decrease in total employment in farming activities. This decrease is in part attributed to increasing urbanization. With the encroachment from metropolitan areas, especially prominent in lower parts of the Basin, agriculture will become oriented toward production of commodities that do not necessitate heavy land requirements. Declines in the potato and tobacco industry are projected to continue while an overall increase in the dairy industry and vegetable output for fresh market is expected.

Output of vegetables for fresh market is projected to increase substantially in the Basin but not in some of the areas that are currently in production. Pressure from metropolitan centers has been reducing the acreage used to produce vegetables in the lower part of the Basin, particularly in CRB VI.

Vegetables for processing are not important in the Connecticut River Basin. However, much of the farm production that still remains can be categorically called "mono-culture" farming. This implies that production is limited to one major crop (i.e. corn for grain). Mono-culture farming tends to deplete the soils natural nutrients, thereby causing the farmer to rely on commercial fertilizers. Consequently, during times of heavy runoff or flooding, these farmlands serve as major non-point sources of nutrient enrichment to the adjacent basin waters.

The most important livestock enterprise on farms within the Connecticut River Basin is dairying. The relative importance of the dairy enterprise increases towards the upper portions of the Connecticut River Basin.

During the winter months the livestock enterprise can have deleterious effects on water quality. The animal excrement during these months is deposited and often spread upon frozen ground. When the spring runoff occurs the nutrients from these deposits are washed into the nearby waterways rather than percolating into the ground as they usually do in the unfrozen periods. This can amount to significant nutrient concentrations since research has shown that the wastes from one dairy cow are approximately equal to that of 17 people.

In spite of these agricultural malpractices, it was noted that man's transition from an agricultural economy to an urbanized one has resulted in the most serious threat to our water supplies. Overcrowding of septic systems in an area, combined sewer overflows, and disregard for the geological constraints are only a few practices which have resulted in domestic sewage short-circuiting to our water bodies. Besides these practices, urbanization has necessitated other new land and water uses that have led to serious problems in water quality. Construction sites without proper erosion control for urban subdivisions, and their linking highways are responsible for tons of sediments per year to be deposited in the basin waterways. Prime examples are the Gale River, a tributary to the Ammonoosuc River, and the Farmington River. Sediment influx causes a smothering and scouring impact upon fish and other benthic organisms and it can interfere with spawning and feeding habits. Other adverse effects from siltation and sedimentation are increased water treatment costs, decreased recreational activities, impairment to navigation, loss of effective reservoir or flood storage and increased costs to industries and hydroelectric plants for accelerated equipment wear and damage.

Enactment of regional legislation requiring the control of erosion from cultivated farmlands, timbering lands and construction sites will do much to decrease the silt influx into the basin's waters.

Besides being responsible for increased sedimentation, timbering practices have been responsible for increased nitrate concentrations in receiving waters. When the land is timbered increased sunlight causes increased activity of nitrate forming bacteria. When precipitation occurs the increased amounts of nitrate produced by the bacteria are carried to the streams by the runoff, making the waters rich in the nutrient nitrogen in the form of nitrate.

Thermal pollution is another problem faced in the Connecticut River basin. Increased use of water for hydroelectric power, cooling towers, and other cooling systems has been responsible for water quality changes in local areas. Increasing the temperature of water leads to reduced oxygen concentrations by lowering the saturation limit. In addition to permitting reduced oxygen concentrations, thermal pollution causes death to benthic organisms through direct heat effects, by causing internal functional aberrations (changes in respiration, growth, etc.), by disrupting the food supply, decreasing resistance to toxic substances and, as mentioned, by causing an oxygen deficiency. Thermal pollution interfers with spawning or other critical activities in the life cycle and allows competitive replacement by more tolerant species. An increase in temperature could also decrease stratification periods and could cause frequent or prolonged algal blooms or upset the biodynamic cycles for those organisms who depend on temperature changes for reproductive habits such as insect hatching and fish spawning. Thermal pollution is a major concern for atomic power plants which discharge millions of gallons per day of used cooling water.

Another problem faced in the Connecticut River Basin is one of minimum flow releases from impoundments. The Connecticut River Basin is one of the most regulated streams in the United States today. Included in the regulatory structures are the numerous hydroelectric dams. The Connecticut River Basin has made great use of its available hydroelectric resources in supplying the power demands of its region. There are 75 plants in the Basin which have an aggregate generating capacity of 641,814 kilowatts.

Hydroelectric power dams are the major intermittent streamflow users in New England. According to the operating principles of pump storage hydroelectric dams, streamflow alteration and storage is often necessary to meet power demands. The net result is often a minimum flow release. These power dams are used as "peaking power" supplies during the hours of intensive electrical demands, being low at night and on weekends, and high during daylight hours of Monday through Fridays. The flow just below a power dam may drop within a few minutes from several thousand to a few hundred cfs when storage to meet power demands is occuring. Streams have suffered erosion problems, dried-up river beds, and physical, chemical, and biological stresses due to the resultant minimum flow releases and the reduction in the streams' carrying capacity. This is an important problem, which should be addressed in any program designed for achieving desired water quality.

Hence, due to the immense expansion of pollution problems, the subsequent loss of valuable water resources and the eminent hazard to human health, the need for government control on discharges and water use became a necessity.

1.4 Standards and Existing Water Quality

Due to the activities in the Connecticut River Basin, the water quality varies from that suitable for drinking with only minimal treatment to a quality which precludes the use of the water for many present day demands. In some areas, the water quality creates nuisance conditions. In accordance with the Water Quality Act of 1965, New Hampshire, Vermont, Massachusetts, and Connecticut established water quality standards for their interstate streams and coastal waters within the Basin. In the Federal Water Pollution Control Act Amendments of 1972, the requirement for established standards was extended to include intrastate waters. The State's standards have been approved by the Federal government, and as such they are subject to both State and Federal enforcement. The water quality standards include use designations for each water body; criteria for measuring the quality of the water; and an implementation schedule for the construction of treatment facilities to achieve said uses. In general, standards require that wastes receive secondary treatment with disinfection, or the industrial waste equivalent before being discharged to a receiving water. The current implementation schedule calls for completion of necessary treatment facilities by about the mid 1970's.

These standards, in effect, are an initial water use plan for the basin arrived at through the political process. They provide for public health, public enjoyment, water supply needs, propagation of fish and wildlife and economic and social development.

Present day technology and practicability of waste treatment require that the adjacent waters accept some portion of the treated waste generated. However, a major goal in the development of the Basin's water resources is to provide aesthetic attractiveness. This objective is not only limited to the Connecticut River Basin, but is exemplified as a national goal in the 1972 Amendments. As stated, "it is the national goal that the discharge of pollutants into the navigable waters be eliminated by 1985; it is the national goal that wherever attainable an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983; and it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited." The residual waste load and the ability of the streams to accept the wastes are important considerations in attaining this goal and setting the interim waste treatment requirements.

During the interim before 1985, there are several other deadlines which deal individually with industrial and municipal wastes. Industries discharging pollutants into the Nation's waters must use the "best practicable" water pollution control technology by July 1, 1977 and the "best available" technology by July 1, 1983. Concerning municipal discharges, all sewage treatment plants in operation on July 1, 1977 must provide a minimum of secondary treatment with one exception. A plant being built with the help of a Federal grant that was approved before June 30, 1974, must comply with the secondary treatment requirement within four years, but no later than June 30, 1978. All publicly owned waste treatment plants will have to use "best practicable" treatment by July 1, 1983. Besides meeting these future treatment requirements, industries and municipalities must meet present and immediate future water quality standards set by the states and endorsed by the Federal government. In many cases, the restrictions on water quality will necessitate more advanced treatment than that proposed by 1977.

Appendix D of the Comprehensive Study lists the individual water quality standards enforced by the States of New Hampshire, Vermont,Massachusetts and Connecticut and subsequently enforced by the Federal government. The criteria selected for governing water quality were chosen by scientists, engineers and other water experts, who determined what substances and how much of each the waterway could assimilate and still be fit for desired uses. The states are now in the process of upgrading their standards and their stream classifications in order to insure the preservation and enhancement of desirable water quality.

Table 1.1 indicates the areas in the presently published standards which have been upgraded by recently adopted or proposed revisions.

Table 1.1

Water Quality Standards Revisions
Adopted by the Connecticut River Basin
States in the Period Nov.-Dec., 1973

TITLE	CONN.	MASS.(1)	N.H.	VT.
Improved Non-degradation policy	yes(2)	yes	no(3)	yes
Silt & Sediment Deposits	yes	no	no	no
Mixing Zones & Zones of Passage	yes	yes	yes	yes
Coliforms for Class C and SC waters	had previously(4)	yes but applicable only during dry weather		had previously
Marine Water Temperature	yes	no	had previously	--
Turbidity	yes	no	yes	yes
Phosphorous policy for Lakes	yes	yes removed numerical standard	yes	yes
Dissolved Oxygen	had previously	yes cold water streams	yes cold & warm water streams	yes warm water lakes

(1) Mass. revisions are still proposed.
(2) Yes - means improved upon.
(3) No - means no action taken on this parameter.
(4) Had previously - adequate limits before revisions.

Connecticut, Massachusetts, and Vermont all improved their non-degradation policy. Connecticut improved its non-degradation policy by prohibiting all discharges to class SA - marine waters. Any freshwater previously classified A was now classified AA and waters of high recreational value previously classified B were reclassified A. This clause now prevented discharges to waters of high recreational value, something that was not prohibited under a B classification. Massachusetts added a clause to its non-degradation policy which prohibited any new discharge to class A, B, or B1 waters upstream from the most upstream existing discharge. Also, no new discharge of wastewater would be permitted in class SA or SB waters. Vermont prohibited the discharges of wastes of domestic origin or of wastes containing pathogenic organisms, prior to treatment, in class A waters.

Connecticut was the only basin state to add a new "silt and sand deposits" clause to their standards. The clause required measures be taken to control and minimize erosion from agricultural lands, road maintenance and construction activity.

All of the basin states adopted a mixing zone and zone of passage policy for their standards. The states' revisions prohibit the creation of lethal conditions in the mixing zones and require that a zone of passage be maintained for fish. In other words, the mixing zone cannot utilize the entire cross section of the stream.

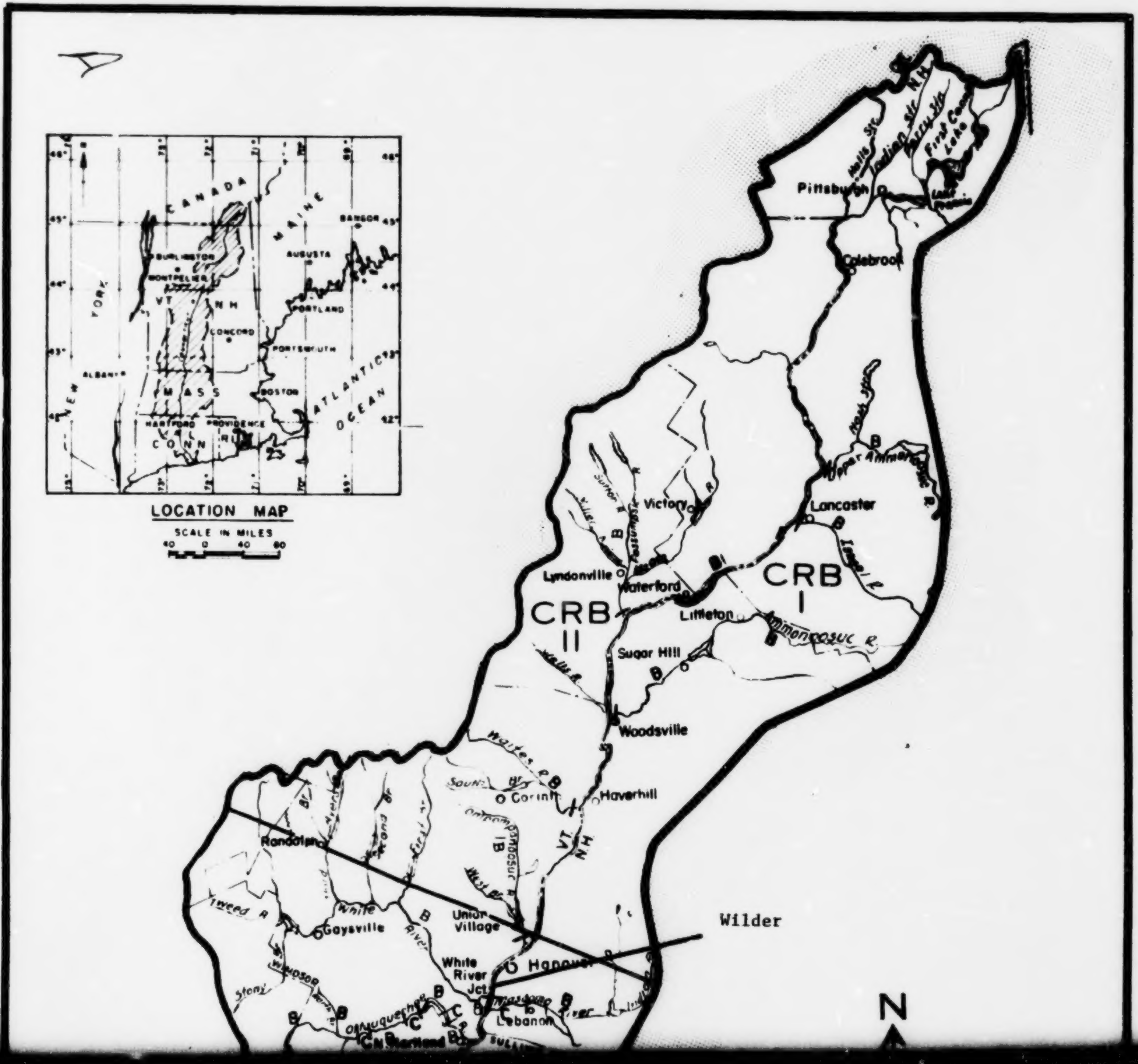
Massachusetts and New Hampshire restricted compliance to coliform limits in class C and SC water only during dry weather. Because of the combined sewer overflows and the lack of immediate funds to correct the problem, the states felt the need for this restriction.

Only Connecticut improved upon their marine water temperature requirements. The State refined their allowable temperature increase and limited the temperature elevation of the receiving waters to be no more than 1.5° F during the period including July, August, and September, unless it could be shown that spawning and growth of indigenous organisms would not be significantly affected.

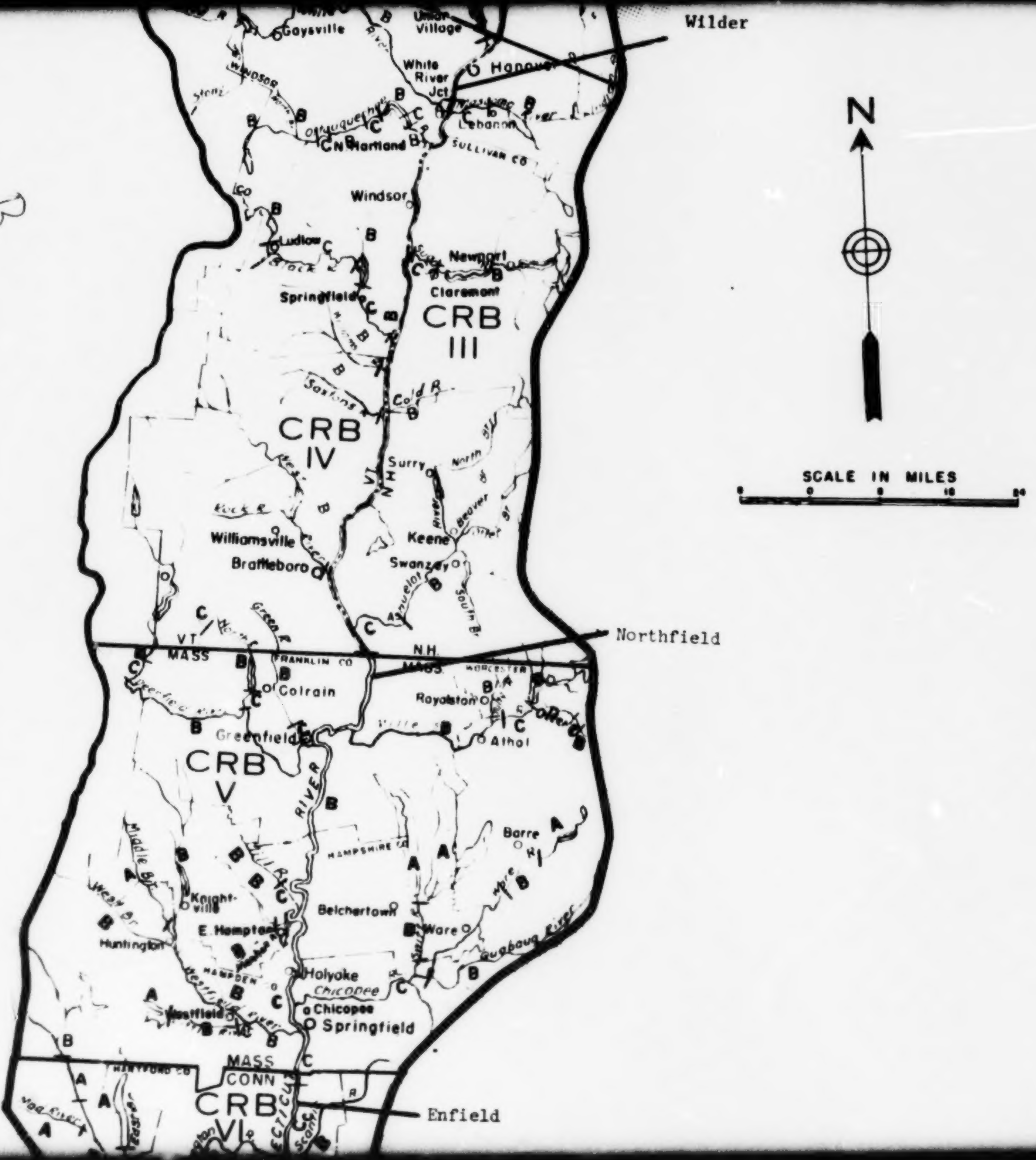
Connecticut, New Hampshire, and Vermont improved their turbidity restrictions. Briefly, the turbidity restrictions were, generally, set to be 10 JTU on cold water bodies and 25 JTU for warm water bodies for most classifications. New Hampshire followed these guidelines before but they were not formally adopted.

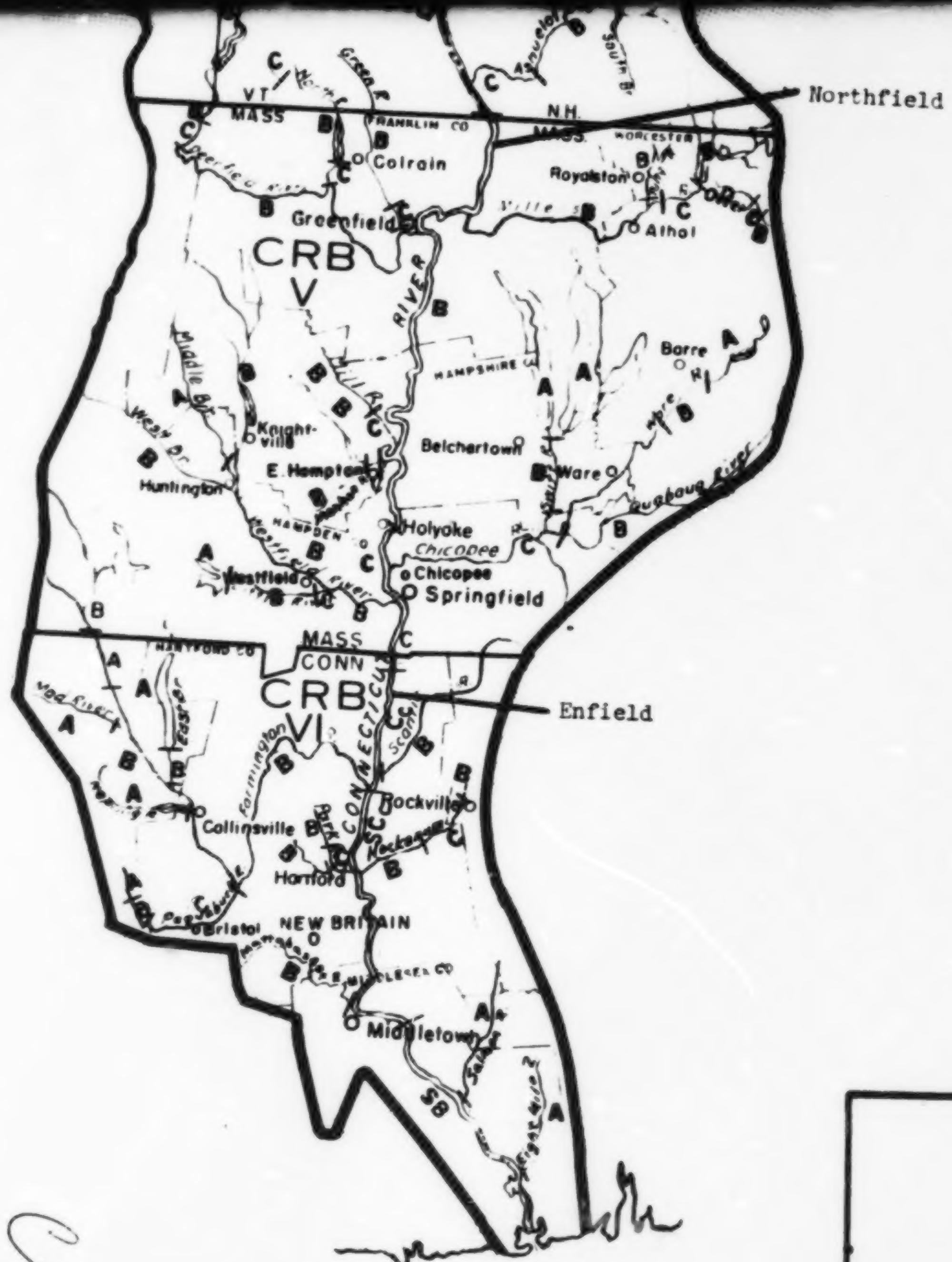
All of the basin states refined their standards in terms of phosphorus discharges to lakes. Massachusetts' revisions removed the numerical limit and stated that all waste sources entering lakes and the feeding tributary streams must have the phosphorous removed to the most feasible extent. Massachusetts, along with

A


LOCATION MAP
SCALE IN MILES
40 0 40 80
CANADA
MAINE
BANGOR
AUGUSTA
BURLINGTON
MONTPELIER
VT
N H
PORTLAND
CONCORD
PORTSMOUTH
NEW YORK
ALBANY
MASS
BOSTON
ATLANTIC OCEAN
HARTFORD
PROVIDENCE
CONN
R I
Pittsburgh
Colebrook
Lancaster
CRB I
CRB II
Victory
Lyndonville
Waterford
Littleton
Ammonoosuc R.
Upper Ammonoosuc R.
Sugar Hill
Woodsville
Haverhill
Corinth
VT.
N.H.
Wells R.
Waites R.
Randolph
Union Village
Gaysville
White River
White River Jct
Hanover
Lebanon
Wilder
Tweed R.
Stony
Ottauquechee
Mascoma River
Hartland
B
C
IB
N

B


Wilder
Union Village
Gaysville
White River Jct
Hanover
Lebanon
Hartland
SULLIVAN CO
Windsor
Ludlow
Newport
Claremont
Springfield
CRB III
Cold R.
Saxtons
CRB IV
Surry
VT
NH
Keene
Williamsville
Brattleboro
Swanzey
South Br.
Ashuelot
Green R.
Northfield
MASS
FRANKLIN CO
WORCESTER
Colrain
Royalston
Athol
Greenfield
CRB V
RIVER
Barre
HAMPSHIRE CO
Middle Br.
West Br.
Knightville
Belchertown
Ware
E. Hampton
Huntington
Quaboag River
HAMPDEN
Holyoke
Chicopee
Westfield
Springfield
MASS
CONN
HARTFORD CO
CRB VI
Enfield
N
SCALE IN MILES
0
5
10
20


Northfield
Enfield
VT
MASS
N.H.
FRANKLIN CO
WORCESTER
HAMPSHIRE CO
HAMPDEN
HARTFORD CO
CONN
MIDDLESEX CO
CRB V
CRB VI
Colrain
Greenfield
Royalston
Athol
Barre
Belchertown
Ware
Knightville
E. Hampton
Huntington
Holyoke
Chicopee
Springfield
Westfield
Rockville
Collinsville
Hartford
Bristol
NEW BRITAIN
Middletown
Green R
Deerfield River
Middle Br
West Br
Mill R
Chicopee
Westfield River
Quaboag River
Ashuelot
South Br
Millers
Swift R
Ware
Farmington
Mad River
CONNECTICUT
RIVER
Scantic
Hockanum
Park R
Salmon
Eightmile R
SB
A
B
C

C

CONNECTICUT RIVER BASIN SUPPLEMENTAL STUDY WATER QUALITY CLASSIFICATION Map 1.2

New Hampshire and Vermont prohibited all new discharges containing phosphorus to above said waters. Connecticut revised their standard to prohibit any phosphorus discharge which raised the ambient concentration in the lake to greater than .03 mg/l.

Massachusetts, New Hampshire and Vermont extended their dissolved oxygen requirements. Massachusetts set a limit of 6 mg/l on cold water streams. New Hampshire set a limit of 6 mg/l on cold water fisheries and 5 mg/l on warm water fisheries, and Vermont established a 5 mg/l limit on Type V waters or warm water lakes, reservoirs, ponds, etc.

Map 1.2 illustrates the water quality classifications established for the Connecticut River. At the present time, many of the limits set for the parameters used to establish these classifications are violated. However, according to the 1972 Amendments, standards should be met by 1977. Once standards are met, the water quality of the basin will be indicated by the limits of the classifications. With the goal of no discharge by 1985, the future water quality of the Connecticut River Basin should steadily improve. At present, there are localized regions where other parameters such as toxic metals, etc., may be critical but these are usually due to local contamination which generally has short exposure time before they are reduced below toxic levels by the receiving waters. Implementation of effluent guidelines for industries has significantly reduced this problem. Future adherence to the requirements of best practicable treatment currently available by 1977 and the best available treatment economically achievable by 1983 will bring these problem areas up to desired standards.

With these efforts and with the future goals established by the 1972 Amendments, which will require more stringent waste treatment practices, it is felt that the waters of the Connecticut River Basin will provide for the protection and propagation of fish, shellfish and wildlife and provide for recreation in and on the water at all points in the basin.

Table 1.2 lists the general uses for the different water classifications found within the basin.

Preceding page blank

Table 1.2

General Use Descriptions for Various Water Quality Classifications Found in the Connecticut River Basin

CLASSIFICATION	USE
Inland Waters	
Class A	Suitable for water supply and all other uses; character uniformly excellent.
Class B	Suitable for bathing, other recreational purposes, agricultural uses, certain industrial processes and cooling; excellent fish and wildlife habitat; good aesthetic value; acceptable for public water supply with appropriate treatment.
Class C	Suitable for fish and wildlife habitat, recreational boating and certain industrial processes and cooling; under some conditions acceptable for public water supply with appropriate treatment; good aesthetic value.
Class D	Suitable for navigation, power, certain industrial processes and cooling, and migration of fish; good aesthetic value.
Coastal and Marine Waters	
Class SA	Suitable for all sea water uses including shellfish harvesting for direct human consumption (approved shellfish areas), bathing, and other water contact sports.
Class SB	Suitable for bathing, other recreational purposes, industrial cooling and shellfish harvesting for human consumption after depuration; excellent fish and wildlife habitat; good aesthetic value.
Class SC	Suitable fish, shellfish and wildlife habitat; suitable for recreational boating and industrial cooling, good aesthetic value.
Class SD	Suitable for navigation, power, and certain industrial cooling water; migration of fish; good aesthetic value.

2.0 STREAM FLOW AND ITS EFFECT ON WATER QUALITY

Before evaluating the effects of extrinsic factors such as effluent discharges and use demands on a stream, the changes in water quality caused by naturally occurring variances in a stream should be determined. Flow variances often induce changes in the physical-chemical composition of a stream. Determining the amount of variance induced by changing flow levels facilitates the differentiation of natural changes from man-induced changes in water quality. Based on this premise, attempts were made to determine the amount of water quality variance occurring in the Connecticut River which can be attributed to flow.

In order to determine the changes in water quality occurring as a result of streamflow variations, the available water quality data found in the Environmental Protection Agency's Storet* file was analyzed. The data was obtained at the three National Network Monitoring Stations on the Connecticut River mainstem. The three stations are located at Wilder, Vermont; Northfield, Massachusetts; and Enfield, Connecticut. The period of analysis extended for 5 consecutive years: 1964 through 1968. The period was selected because it represented the most recent period of 5 years which had enough data to provide a more secure analysis. In 1969, the sampling pattern was changed and samples were taken on a much more infrequent basis.

Procedure A statistical analysis was performed on selected parameters for the periods of March through May, the high flow period and July through September, the low flow period, in order to determine whether there is any significant relationship between flow and the selected water quality parameters of temperature, DO, BOD, COD, pH, alkalinity, solids, NH_3-N_2, phosphates, hardness, sulfates and chlorides. A linear regression provided a means of summarizing the various relationships between each flow group and each parameter for which there was sufficient data available. Flow was considered the independent variable and the water quality indicators were considered dependent variables.

---

* Storet is the acronym used to identify the computer-oriented U.S. Environmental Protection Agency management information system for STOrage and RETrieval of water quality, municipal and industrial waste facility inventory, water quality standards compliance, fish kill, oil spill, construction cost, and other related data. The system maximizes availability of data collected by diverse agencies and locations. Rapid, inexpensive storage, retrieval, and analysis of large volumes of data are possible. Storet has evolved from a storage-retrieval system for raw water quality data to a storage-retrieval-analysis system for water quality, waste facility, and other data. Storage, retrieval, and analysis of water quality data approximately equals other uses. Sampling locations may be defined by hydrologic index and/or geographical coordinates to allow retrieval on a stream flow or geographical basis. Options in storage, retrieval and analysis of water quality and other data are so numerous that their selection and use constitutes "programming".

Attempts to subdivide the two main flow groups into a series of smaller consecutive groups tended to mask any correlation that appeared when the data was handled in terms of the two major groups. This was the first indication that the significance of flow on water quality changes would be small.

In addition to showing any linear trends in the data, the regression would indicate whether the type of relationship shown in one flow group was the same as the one indicated in the other flow group. If a significant relationship was indicated, the type of relationship, i.e. direct or inverse, and the strength of the relationship would be indicated by the slope or correlation coefficient of the fitted line.

The analyses were performed in both pounds per day and milligrams per liter except for temperature and pH. The milligrams per liter or concentrations were used in the analysis of the data since the transformation from concentrations (mg/l) to loading (lbs/day) induces an artificial relation with flow by assigning a factor of flow to the dependent variable. The data presented in terms of loading is included in the Appendix B in order to facilitate any future need.

Appendices A and B contain the regressions for concentrations and loads generated from the data observed, and plot not only the observed values, but also the values predicted by the regressions. The X and Y means, the Y intercept of the regression line, the correlation coefficient, and the F value are recorded for each parameter. In some cases the values determined held too many digits and the computer printed a series of asterisks indicating this.

The correlation coefficient or nearly equivalently the regression coefficient indicates the significance of the linear relationship. To determine the significance of the relationship, the hypothesis $H_0 : \beta = 0$ was tested using the statistical "F" test. $\beta = 0$ means the population regression coefficient = 0, which generally indicates that the population correlation coefficient = 0, thus indicating no linear relationship exists between the two parameters. Using the F - Test, if this hypothesis could be rejected with the probability α remaining low, α being the probability that the hypothesis is actually true and is falsely rejected, then there exists a significant relationship between flow and the parameter tested. α in the statistical analyses was always less than or equal to .1.

Table 2.1 indicates the type of relation observed for the flow group examined, the level of significance, and the correlation coefficient for the concentrations. It indicates that Wilder Station, in many instances, had insufficient data to be used in comparison with the Enfield and Northfield Stations. Of the 12 parameters examined, only pH, alkalinity and hardness exhibited similar trends at most stations. The pH strongly showed that there was little or no correlation between its value and flow, while alkalinity and hardness showed that an inverse relation existed between their concentrations and flow.

pH and alkalinity in natural waters can be correlated through the carbonate equilibrium. Since the pH varied from 6.2 to 7.8 at the observed stations, the carbonate equilibrium indicates that most of the alkalinity will be in the form of bicarbonate ions. The fact that both the alkalinity and hardness concentrations decrease with increasing flows while the pH remains unaffected (i.e. no relation indicated) is explained by dilution and the buffering capacity of water. The higher flows tend to dilute the alkalinity and hardness concentrations but the buffering capacity of the stream kept the pH relatively unaffected.

The tendency for the pH to be in the neutral range and the observed low hardness concentrations indicate that there is very little basic carbonate material in the Connecticut River Valley in the form of limestone deposits or thick topsoil layers. In general, hard waters tend to originate in areas where the topsoil is thick and limestone formations are present; and soft waters tend to originate in areas where the topsoil is thin and limestone formations are sparse or absent.

Although the analysis failed, in most instances, to show any consecutive relationships, the reasoning and methodology used was considered more valid than the results indicated. There are many factors which could be responsible for such sporadic results. Many inherent factors such as point and non-point discharge sources, runoff, volume and periodicity of wastes discharged, ice jams, and precipitation, to name just a few, are responsible for some sporadic observations. However, based upon the numerous data sources supplying the information to Storet, experimental error, the lack of sufficient data, and the amount of incorrect data that could be traced and disapproved; it is felt that the lack of congruent relationships between the stations is primarily man-induced.

Besides being statistically significant, it is important to determine the implication of any significance. If the correlation coefficient r is squared, the resulting number is a measure of the

Table 2.1

Relationships Determined by Linear Regression Analysis for Concentrations

PARAMETERS	ENFIELD		NORTHFIELD		WILDER	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Temperature	α = .10 2 r = -.22	0	0	0	-	-
Dissolved Oxygen	α = .01 1 r = .51	0	α = .025 1 r = .34	0	-	-
BOD	α = .025 2 r = -.32	α = .01 2 r = -.57	α = .10 2 r = -.24	0	-	-
COD	0	α = .01 2 r = -.46	0	0	-	-
pH	0	0	0	0	0	-
Alkalinity	α = .01 2 r = -.74	α = .01 2 r = -.41	α = .01 2 r = -.55	α = .025 2 r = -.36	α = .10 2 r = -.30	0
Solids	0	α = .05 2 r = -.33	α = .01 2 r = -.40	0	α = .10 2 r = -.51	0
NH_3-N_2	0	α = .01 2 r = -.36	0	0	-	-
Phosphates	α = .05 2 r = -.28	α = .01 2 r = -.56	0	α = .10 1 r = .27	-	-
Hardness	α = .01 2 r = -.80	α = .01 2 r = -.54	α = .01 2 r = -.50	α = .10 2 r = -.26	0	0
Sulfates	0	α = .01 2 r = -.41	0	α = .025 1 r = .33	α = .10 2 r = -.33	α = .05 1 r = .41
Chlorides	α = .01 2 r = -.39	α = .01 2 r = -.37	α = .01 2 r = -.40	0	0	0

- - Insufficient Data
2 - Inverse Relation
1 - Direct Relation
0 - No Relation

α = level of significance
r = correlation coefficient

amount of variation in a parameter that may be explained by the parameter's relation to flow. For example, by squaring the correlation coefficient for dissolved oxygen determined at Enfield during the high flow period, one finds that 25% of the variation in dissolved oxygen is indicated as being related to flow and 75% as being related to other factors. The significant correlations are generally between .3 and .5 which indicate that 10% to 25% of the parameter variation can be attributed to variation in flow. Thus, the significant relations are weak and the correlations are mild.

The above evidence supports initial indications that the effects on water quality caused by flow variation are small and that most of the variation in the parameters measured must be due to other factors such as effluent discharges, runoff, surrounding environments, use, and experimental error.

3.0 NUTRIENT LOSSES TO THE BASIN

A nutrient is anything that is necessary for the promotion of growth, repair of tissue, or energy source of an organism. Nutrients consist of organic and inorganic matter which fertilize the waters. Organic matter in soluble form is food for bacteria which, if sufficiently fed, may dominate the biological system leading to algal blooms and eutrophic conditions. Thus, any water body is an ecosystem in which the intensity of biological and chemical changes is determined by the nutrient input. The ten essential elements of growth are carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, and iron. Silica, trace metals, and vitamins are also nutrients that should be considered. Previous investigations on various eutrophic lakes have attempted to determine which nutrient limits the growth of an algal population when all other nutrients are in excess. Accordingly attempts have been made to control primary productivity by controlling what is thought to be the limiting nutrient.

All nutrients are cyclic in nature. However, due to the abundance of some or a lack of understanding of the cyclic intricacies of others, the major nutrients thought to be a controlling factor in eutrophication are carbon, nitrogen, and phosphorus. The relative roles of importance of each of these elements in causing eutrophication is subject to much debate. However, due to their cyclic nature and some extenuating circumstances, one that may be limiting at one point may not be limiting at another.

Due to several reasons, phosphorus is felt by most to be the key point of attack on limiting nutrient enrichment. Nitrogen is hard to control because it occurs in most wastewaters largely in the form of ammonium and organic compounds. In some effluents it occurs as nitrates and nitrites. There is significant removal of combined nitrogen from the soils by surface runoff and infiltration. This nitrogen usually enters the surface water or groundwater in the form of nitrates. Finally, some forms of blue-green algae are capable of fixing nitrogen from the atmosphere, in the absence of adequate sources of inorganic and organic nitrogen, providing other nutrients are present in sufficient quantity.

Carbon in the form of CO_2 is necessary for photosynthesis. Due to the abundance of carbon dioxide in the atmosphere and in the carbonate alkalinity system of water, carbon is another element that would be difficult to control. In addition, organic carbon serves as food source for heterotrophic organisms which in turn produce more CO_2 which in turn can be used by algae. The new supply of CO_2 allows algae to reproduce at an increased rate providing more food for the heterotrophs, leading to an unruly cycle which eventually leads to mass algal blooms and eutrophication.

Phosphorus, one of the most important elements in biological systems, appears to be the most logical nutrient to attack. While carbon and nitrogen both have atmospheric reservoirs available to aquatic environments, phosphorus has only a sedimentary cycle. Effective use of dissolved oxygen diffusers and mechanical mixing have, in some cases, formed an oxidized sediment layer which has isolated the soluble forms of phosphorus from the water and sealed them in the sediments.

Phosphorus is the most limiting of the nutrients, as is indicated by the nitrogen : phosphorus ratio. The ratio varies with the water, season, temperature, and geological formation, and may range from 1:1 or 2:1 to 100:1. In natural waters, the ratio is often very near 10:1.

Although phosphorus is really the most limiting of the three nutrients, many feel that because of the algae's ability to store phosphorus and release it upon decomposition, eutrophication control from this angle is hard pressed. However, as shown in Table 3.1, only phosphorus is known to be growth controlling and controllable by man.

Table 3.1

* Comparison of Various Plant Nutrients in Respect to:
(A) Whether They are Ever Growth-Controlling in Lakes, and
(B) Whether They are Controllable by Man.
Note that Phosphorus is the Only Element Meeting Both Requirements.

NUTRIENT	A	B	NUTRIENT	A	B
Hydrogen	no	no	Chlorine	no	no
Boron	no	no	Potassium	no	no
Carbon	rarely	no	Calcium	no	no
Nitrogen	yes	partly	Manganese	sometimes	no
Oxygen	no	no	Iron	sometimes	no
Sodium	no	no	Cobalt	rarely	no
Magnesium	no	no	Copper	no	no
Aluminum	no	no	Zinc	no	no
Silicon	yes**	no	Molybdenum	sometimes	no
Phosphorus	yes	yes	Iodine	no	no
Sulphur	rarely	no			

* Vallentyne, J.R. 1970, "Phosphorus and the Control of Eutrophication", Canadian Reasearch and Development 3: 36-43, 49.

** Diatoms only.

Limited laboratory studies made to date indicate that different species of algae have somewhat different phosphorus requirements with the range of available phosphorus usually falling between .01 and .05 mg/l as phosphorus. It is believed that allowable total phosphorus depends upon a variety of factors; e.g. type of water, character of bottom soil, turbidity, temperature, and especially desired water use. Allowable amounts of total phosphorus will vary, but in general it is believed that a desirable guideline is .1 mg/l for rivers and .025 to .05 mg/l where streams enter lakes or reservoirs.

Phosphorus comes from a variety of sources. Natural sources constitute a small part of the phosphorus influx. Since natural influxes have a low solubility, man's activities have contributed almost all of the phosphorus that has been related to eutrophication. The major sources of phosphorus entering fresh waters are domestic sewage effluents including detergents, animal and plant processing wastes, fertilizer and chemical manufacturing spillage, various industrial effluents, and to a limited extent, erosion materials in agricultural runoff.

Normal domestic waste waters contain 15 to 60 parts per million nitrogen and 5 to 20 parts per million phosphorus. Phosphorus that does not go into solution during decomposition may accumulate in bottom deposits and be redistributed in overturns unless effectively sealed off by an oxidized layer of sediments.

Phosphorus entering an ecosystem may produce a high oxygen demand. One milligram of phosphorus from an organic source demands about 160 milligrams of oxygen in a single pass through the phosphorus cycle to complete oxidation. Since it is estimated that one pound of phosphorus yields 30 pounds of dry weight algae, the oxidation of organic matter, the growth of which has been induced by adding phosphorus, may also bring about a great reduction of oxygen in a lake or stream. Thus, if phosphorus is to be controlled, the sources need not only be eliminated, but the receiving waters should be treated as well, especially if these waters are impoundments or discharge to impoundments.

Using the same Storet file indicated in the above section, attempts were made to determine the nutrient losses to the basin. Nutrient loads carried by the basin's waterways are necessary for algal production in the basin. Excessive nutrient loads cause blooms and eutrophic conditions to occur in the impoundments of the basin. Excessive nutrient loads can indicate a high degree of runoff from agricultural lands or pastures. It can also indicate the discharging of large volumes of inadequately treated wastewater, especially if sharp increases in nutrient loads occur around urban centers or downstream from outfalls.

Nutrients are primarily measured in terms of phosphates and nitrates or ammonia nitrogen. Unfortunately the Wilder Station is deficient in nutrient data.

Table 3.2 estimates the amount of nutrients carried by the Connecticut River, in the form of phosphates and ammonia-nitrogen, at the Northfield and Enfield sampling stations for an average high flow and low flow. From this table, it can be assumed that the daily nutrient loads lost to the stream at Northfield range between 1,300-8,000 lbs/day for NH_3-N_2 and 9,000-13,000 lbs/day for phosphates at average flows ranging from 3,000 to 17,000 cfs. The daily nutrient loads passing the Enfield Station range between 13,000-33,000 lbs/day for NH_3-N_2 and 11,000-30,000 lbs/day for phosphates for an average flow ranging from 6,000 to 26,000 cfs. The loads measured at each station show the net cumulative load acquired from the drainage area above the sampling station. Thus the load measured at Enfield reflects partially the load carried at Northfield.

The apparent anomaly indicated between the phosphate and ammonia-nitrogen load ratio exhibited at the two stations is probably a result of the individual sampling locations. The high levels of ammonia-nitrogen registered at Enfield are caused by the tremendous load of ammonia-nitrogen discharged into the river in the Springfield Metropolitan area just above Enfield. There is only a small discharge of ammonia-nitrogen to the river above Northfield.

Table 3.2

Nutrient Losses *Estimated from Storet Data
Taken During High and Low Flow Periods

STATION		NH_3-N_2	PHOSPHATES
Enfield:	High	32,930 lbs/day	29,156 lbs/day
	Low	13,526 lbs/day	11,519 lbs/day
Northfield:	High	7,916 lbs/day	12,697 lbs/day
	Low	1,322 lbs/day	9,247 lbs/day

* Mean

Based upon the limited accuracy of the data and the numerous sampling sources used during this flow period, the results should only be used to indicate a possible order of magnitude. Even to this degree, the enormous volume of nutrients lost daily to the basin's waterways should encourage strong erosion controls on agricultural lands, controls on urban runoff and combined sewer overflows, more advanced wastewater treatment and probably better practices in sludge disposal.

The estimated nutrient loads carried by the Connecticut River do not account for those nutrients removed from the stream by oxidation and utilization, or those that are resuspended and hence, as such, are probably conservative. The nutrients measured are taken from samples which actually contain the net concentrations carried at the Northfield and Enfield Stations.

By measuring the amount of effluent being discharged from the municipal facilities and using a conversion factor for nitrogen and phosphorus, an estimate indicating the amount of nutrients which could be removed by expanding existing facilities to tertiary treatment is calculated. The calculations are based on average values for the nutrients being discharged in domestic wastes from municipal facilites in the basin.

Using a factor of 7-10 mg/l of phosphorus and 15-35 mg/l of nitrogen as the concentrations of these nutrients in domestic waste waters, the amount of the nutrients capable of being removed is determined in Table 3.3 for the basin above Northfield and between Northfield and Enfield.

Table 3.3

Amount of Nutrients Capable of Being Removed by Upgrading Existing Municipal Facilities to Tertiary Treatment

Nutrient factor X Sum of flows from existing treatment plants X 8.34 = Pounds /day of nutrients capable of being removed.

	NITROGEN	PHOSPHORUS
Above Northfield	1,631-3,805 lbs/day	761-1,087 lbs/day
Between Northfield and Enfield	8,236-19,218 lbs/day	3,844-5,491 lbs/day

The figures listed in Table 3.3 illustrate the need for advanced waste treatment especially in the urbanized areas in the lower portions of the basin. The figures presented do not include those areas where plants are being constructed or planned. Nor does it account for the nutrients released through agricultural or other runoff. It is apparent, however, that the amount of nutrients contributed by municipal facilities is significant and the removal of this portion of the nutrient contributions to the basin represents a major advance in the battle against nutrient enrichment.

The development of large scale "mono-culture" farming has resulted in nutrient problems. Rather than being a point source of contaminants, nutrient influx from runoff represents a non-point source of nutrient entry and as such is difficult to control. Monoculture farming tends to deplete the soils' natural nutrients, thereby making it necessary to add manufactured fertilizers. Through poor methods of application and uncontrolled erosion, this fertilizer eventually finds its way to water bodies where it aids in eutrophication. Much is being done to reduce the need for excessive applications of fertilizers and to reduce the rate of leachates from crops through contour plowing and crop rotation.

Another agricultural malpractice has been through the disposal of domestic animal wastes. As mentioned previously, the wastes from these animals is often spread on frozen ground. Since the ground is frozen, when the snows begin to melt and the Spring rains begin, the nutrients from this manure are carried to the water bodies in the runoff that results. *Figures 3.1, 3.2 and 3.3 show how the different cultural developments have resulted in nutrient enrichment of our waters.

In addition to nutrients derived from sewage treatment plants, urbanized areas offer another major source of nutrient influx in the form of stormwater runoff. As previously noted, shock loading effects from storm runoff have occurred around major cities. Combined sewer overflows in many cities compound the problem by allowing sewerage to enter the water bodies along with the stormwater during periods of excessive rainfall without adequately treating the waste.

---

* Sawyer, Clair No., "The Need for Nutrient Control", Journal Water Pollution Control Federation, March 1968, Part 1, pp. 363-370.

NOTE: It is felt that the procedures used in the above two sections were valid but that inadequate data and poor sampling and recording techniques hampered more accurate results. Present environmental demands have resulted in new monitoring systems, better analyses, more thorough sampling practices and more accurate data collecting by the States and Federal agencies. The information obtained is presently being recorded in the Storet System and should offer much greater reliability for future work as the present data bank increases.

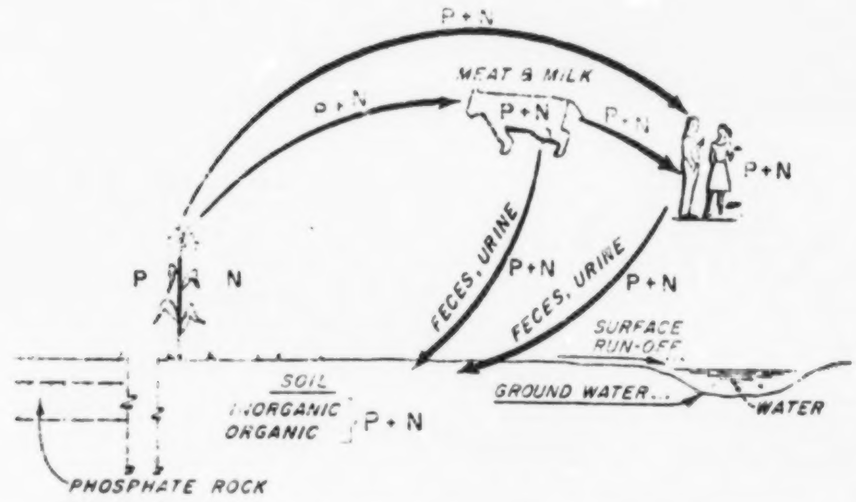

P+N
MEAT & MILK
P+N
P+N
P+N
P+N
P
N
FECES, URINE
P+N
FECES, URINE
P+N
SURFACE
RUN-OFF
SOIL
INORGANIC
ORGANIC
P+N
GROUND WATER...
WATER
PHOSPHATE ROCK

FIGURE 3.1 Phosphorus and nitrogen distribution in an agrarian economy.

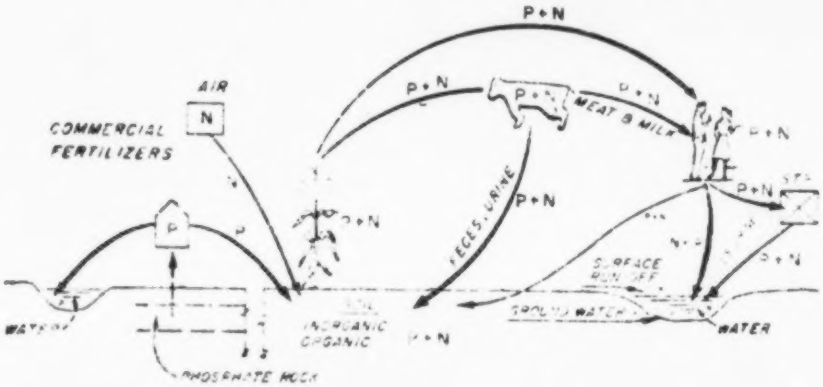

P+N
AIR
N
P+N
P+N
MEAT & MILK
P+N
COMMERCIAL
FERTILIZERS
N
P
P
P+N
FECES, URINE
P+N
P+N
SURFACE
RUN-OFF
SOIL
INORGANIC
ORGANIC
P+N
GROUND WATER
WATER
WATER
PHOSPHATE ROCK

FIGURE 3.2 Phosphorus and nitrogen distribution in a simple urban economy.

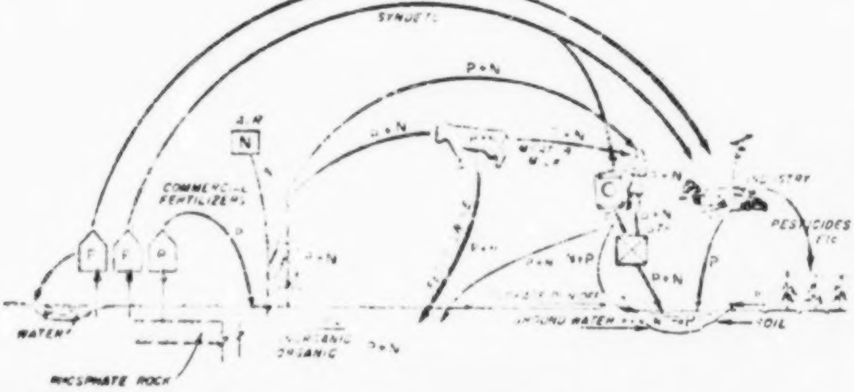

P
SYNDETS
P+N
AIR
N
P+N
P+N
C
COMMERCIAL
FERTILIZERS
INDUSTRY
P
P
P
P
PESTICIDES
ETC
P+N
P+N
P+N
N+P
P+N
P
WATER
GROUND WATER
SOIL
INORGANIC
ORGANIC
P+N
PHOSPHATE ROCK

FIGURE 3.3 Phosphorus and nitrogen distribution in a complex urban economy.

4.0 ESTIMATED SILT LOSSES TO THE CONNECTICUT RIVER BASIN

Erosion and sediment buildup often exert a considerable impact on the ecological, economical and social activities in a river basin. Erosion and siltation can occur naturally within a stream as a result of stream bank erosion and natural rechannelization of a stream bed or it can be induced by external forces acting on the drainage basin such as forest fires, precipitation, winds, agriculture, silviculture, land development practices, and stream flow regulations.

Unmistakably man's activities have been the primary cause of most severe siltation problems. Poor agricultural and construction practices have led to the degradation of many of our waterways and valuable soil resources. Consequences of excessive erosion and sedimentation have been the reason for the enactment of much needed local legislation controlling erosion around newly excavated or exposed construction sites.

The transportation of eroded material and its subsequent deposition can adversely affect the water quality by increasing turbidity and suspended solids. Further, erosion and sedimentation can affect the uses made of the water. High turbidities and suspended solids may be harmful to aquatic life directly by causing gill scour and abrasion of fish and other benthic organisms. Also, sedimentation may interfere with spawning and feeding habits. Water treatment costs, recreational activities and navigation are also affected by high concentrations of suspended material and sedimentation. Loss of effective reservoir or flood storage due to sediment buildup, loss of aesthetic and recreational areas due to silt suspension and buildup, increased costs to industries and hydroelectric plants, who can suffer accelerated equipment damage due to high silt concentrations, and migrating sandbars are some of the problems caused by high silt loads. In times of flood, it is often the displaced sediment that exacts a damaging toll. Once the water recedes the mud remains posing costly removal procedures.

Table 4.1 indicates the amount of sediment carried by the Connecticut River System at various points in the Basin. The suspended sediment figure is a composite of both organic and inorganic loads, however, and at this time, there is no breakdown as to what proportion of the sediment load is actual silt losses. The data collected by the U.S. Geological Survey covers the period from 1965 to 1973. The data for this period was grouped into the four seasons of the year with Fall being considered September through November, Winter being considered December through February, Spring being considered March through May, and Summer being considered June through August. The maximum, minimum and average stream flows and stream loads were determined and a statistical correlation coefficient

Table 4.1

Suspended Sediment Loads At Various Points and Various Time Periods
in the Connecticut River Basin Measured During 1965-1973

Name	Season	Min. Load Lb/Day	Max. Load Lb/Day	Average Load Lb/Day	Min. Flow CFS	Max. Flow CFS	Ave. Flow CFS	#Pairs Considered	Correlation Coefficient
East Branch Tully River Near Anthol, Mass.	Summer/Fall	61.41	939.04	1,651.40	2.2	16	66.37	5	.99
	Winter	21.36	4,806.0		4	180		4	.93
	Spring	122.82	3,956.94		24	172		16	.22
	Yearly	21.36	4,806.0		2.2	180		25	.69
Millers River at South Royalston, Mass.	Winter	4,645.8	42,720.0	17,395.28	62	250	190.67	12	.93
	Summer/Fall	4,026.36	20,185.2		65	180		6	.28
	Spring	4,314.72	31,719.6		110	477		15	-.29
	Yearly	4,026.36	42,720.0		62	477		33	.34
Westfield River near Westfield, Mass.	Fall	2,274.84	52,116.4	36,759.23	107	1220	759.3	7	.93
	Winter	4,405.5	115,290.6		520	1270		6	.39
	Spring	5,927.4	71,556.0		814	1110		5	.30
	Summer	3,956.94	38,544.12		231	802		6	.59
	Yearly	2,274.84	115,290.6		107	1270		24	.64
Westfield River at Huntington, Mass	Summer	517.93	8,090.1	10,010.72	21	303	276.3	6	.60
	Fall	277.69	1,936.48		11	148		9	.65
	Winter/Spring	1,772.83	47,419.2		65	1110		13	.60
	Yearly	277.68	47,419.2		11	1110		28	.81
Quaboag River at West Brimfield, Mass.	Summer/Fall	149.52	8,769.28	23,024.75	21	821	552.3	11	.63
	Winter/Spring	1,265.58	81,915.6		187	1180		11	.58
	Yearly	149.52	81,915.6		21	1180		22	.83
White River at West Hartford, Vt.	Fall	822.36	2,069,944	1,912,036.1	132	2190	2,937.13	12	.84
	Winter	371.40	1,699,188		355	4580		11	.23
	Spring	27,340.80	11,444,668		640	14,100		10	.92
	Summer	1,602.0	52,332		100	1,400		16	.68
	Yearly	371.40	11,444,688.		100	14,100		49	.81
Ammonoosuc River at Bethlehem Junction New Hampshire	Fall	694.2	21,616.32	21,320.62	30	184	269.38	8	.74
	Winter	395.16	13,617.0		60	106		12	-.16
	Spring	1,521.9	122,553.0		49	1,350		9	.73
	Summer	1,196.16	8,971.20		65	311		7	.43
	Yearly	395.16	122,553.0		30	1,350		36	.68
Passumpsic River at Passumpsic, Vt.	Fall	2,499.12	45,763.8	111,534.58	199	857	701.5	8	.82
	Winter	1,335.0	36,045.0		170	750		7	.55
	Spring	9,932.4	723,303.0		310	2620		6	.97
	Summer	587.4	72,810.9		22	684		6	.93
	Yearly	587.4	723,303.0		22	2620		27	.87
Beaver Brook at Wilmington, Vt.	Fall	22.42	88,110.0	3,471.45	1.2	110	38.91	5	.93
	Winter	18.15	4,720.56		3.4	85		11	.80
	Spring	158.59	13,355.34		5.1	74		10	.80
	Summer	2.02	683.52		.6	32		9	.95
	Yearly	2.02	13,355.34		.6	110		35	.89
Williams River at Brockways Mills, Vt.	Fall	64.08	10,693.6	8,616.09	12	458	359.75	8	.95
	Winter	1,441.80	19,224.0		32	600		11	.67
	Spring	1,746.18	117,480.0		109	1100		10	.89
	Summer	58.74	23,752.32		11	556		10	.91
	Yearly	58.74	117,480.0		11	1100		39	.90

was determined to indicate the degree of correlation between sediment load and flow. The correlation coefficients can be used, as in section 2.0 to indicate how strong the relationships are. By using a standard statistics table, confidence limits can be placed around the correlation coefficients if desired.

The data indicate that the dominant sediment loads and flows occur during the winter and spring. The high flows tend to unfreeze normally frozen ground in the winter causing more sediment to be subjected to erosion. This coupled with the higher transport capability of the stream and the lack of vegetative cover, which normally retards erosion and removes some precipitation through evapotranspiration, partially explains the predominance of heavy sediment loads in the winter and spring months. Ice jams during the winter and spring months tend to scour the river bottom resuspending the sediment already there.

Because primary production during the winter and early spring is low, most of this sediment load should be either inorganic in nature or organic detritus material that washes into the stream. However, high flows do tend to resuspend and remove accumulated bottom sediments which would normally exert oxygen demands on the stream over extended periods. The spring freshet provides high flows and cleans the stream bed just prior to usually the most dangerous season, summer, when stream flows are low and rates of decomposition, productivity and oxygen demands are high.

The flows and sediment loads in the winter and spring show the least correlation due to the unstable flow conditions that exist in the basin during these months. It is during the more stable flow regimes of the summer and fall that the generally higher degrees of correlation occur.

Squaring the correlation coefficient gives an estimate on the proportion of variation in the sediment load that may be attributed to flow. After reviewing the correlation coefficients, it is apparent that the sediment loads in most cases are dependent upon flow to a significant degree. The major discrepancies are thought to be due to sampling error.

Based upon the data in Table 4.1 from nine stations located in the basin, an attempt is made to determine for the entire Connecticut River Basin a very rough estimate for the amount of sediment transported during the high sediment load period of winter and spring, and the low sediment load period of summer and fall. This final estimate is based on the assumption that the erosion characteristics of the basin are typified in the tributaries sampled. The station at Huntington, Massachusetts on the Westfield River is excluded because it is felt that the sediment load at this station is taken into account at the lower station near Westfield, Massachusetts. The results are shown in Table 4.2.

Table 4.2

Calculations:

$$\text{Area of basin} \times \frac{\text{lbs/day carried by tribs studied}}{\text{area of tribs studied}} = \text{lbs/day carried by basin}$$

Sediment Loads at Various Points in the Basin

River	Average Flow cfs Winter/Spring	Average Flow cfs Summer/Fall	Average Load lbs/day Winter/Spring	Average Load lbs/day Summer/Fall	Drainage Area Sq. Miles
E. Branch of Tully	77.7	6.94	1,396.68	333.13	50.4
Millers	211.41	98.83	17,202.04	10,923.00	187.
Westfield	892.73	376.23	41,719.55	14,557.69	497.
Quaboag	496.50	188.73	27,702.75	2,949.64	151.
White	2,634.14	506.31	797,686.14	86,718.10	690.
Ammonoosuc	236.95	115.38	12,850.72	3,138.88	87.6
Passumpsic	993.31	402.43	143,643.15	22,085.93	436.
Beaver Brook	23.55	15.35	1,752.86	6,438.50	6.38
Williams	243.00	152.06	8,842.17	3,437.11	103.
Total	5,809.29	1,862.26	1,052,796.06	150,581.98	2,208.38

Drainage area of entire Connecticut River System: 11,136 square miles

Winter/Spring

$$11,136 \times \frac{1,052,796}{2,208} = 5,309,754 \text{ lbs/day}$$

Summer/Fall

$$11,136 \times \frac{150,582}{2,208} = 759,457 \text{ lbs/day}$$

Thus, there is a range from approximately .75 million to 5 million pounds of sediment carried by the Connecticut River each day. This may not be a very large amount when the size of the drainage area and the probable amount of resuspended existing sediments are considered in the estimate. Nonetheless, the deposition of eroded sediments has a cumulative effect on the stream bed until the sediments are moved out by high flows.

Table 4.3 illustrates the amount of dredging necessary to maintain the commercial navigation channel in the estuary between Hartford and Old Saybrook, Connecticut for 1960 to 1972. Using the quantities of sediments dredged as an estimate of the silt load carried and deposited by the river in a given period has its drawbacks. This is due to a series of factors including such items as (1) not all of the bars dredged are done in a single year, and (2) payments for dredging and quantities dredged extend to payment lines, and therefore, the quantities may not necessarily reflect actual quantities, recently deposited, because of overdredging on the part of the contractor. However, studies by the Corps of Engineers do indicate that, although a portion of the sediment at the mouth of the river is deposited during alongshore movement of sediment, much of the deposition above the mouth comes from excavated soil moving back into the channel from nearby spoil areas. And, the sediment derived from erosion sources within the Basin is a minor source of the material deposited in the navigation channel.

In Vol. II, Appendix C, page 48 of the Connecticut River Basin Coordinating Committee, 1970 - "Comprehensive Water and Related Land Resources Investigation, Connecticut River Basin," it was found that "the effects of sedimentation have been considered in the determination of storage requirements for reservoir projects. In New England, however, the predominance of forest cover throughout the watersheds, the hard, crystalline bedrock and the compact, erosion-resistant glacial deposits which occur throughout the region all tend to minimize erosion and consequent sedimentation. This conclusion is supported by sedimentation observation programs initiated by the Corps of Engineers at 14 of its reservoirs in New England including 8 reservoirs in the Connecticut Basin. Measurements have been taken at these reservoirs for periods up to 28 years with an average length of about 14 years. The records at all reservoirs indicate that insignificant amounts of sedimentation or deposition have occurred. Although specific allocation has not been required for sediment storage in the past, the problem will continue to be fully considered and a judgment made for future individual sites."

Vol. III, Appendix D p. 87 of the Comprehensive Study indicates that "Observed sediment loads may not be the result of soil erosion entirely, but may be a combination of the erosion of

Table 4.3

Army Corps of Engineers Dredging Records in the Connecticut River Basin Estuary - Measured in Cubic Yards

	1959	1961	1962	1964	1965	1968	1970	1972 Contract Estimates
Nubuc Bar	24,190	18,695		30,684			23,756	
Pistol Point Bar	41,132			10,646		25,735	22,117	
Portland Bar	31,605							
Rock Landing Bar	15,451			26,640				
Haddam Island Bar	31,698		18,240			17,316	9004	
Glastonbury (2 piers)		47,197						
Mouse Island		17,190						25,000
Sears Upper		12,744		7,943		9,287		30,000
Higganum Creek		14,973					15,618	
Calves Island		23,372					15,012	
Sears Shoal		239	25,248			22,018		76,000
Saybrook Outer Bar		51,626					64,442*	
Saybrook Outside		5,387						
Higganum Creek Outside		643						
Wethersfield Cove			30,511					
Essex Cove			68,365					
Dividend Bar				29,688				32,000
Paper Rock Shoal				10,139				6,000
Cobalt Shoal				15,755				11,000
Essex Shoal				29,850				
Ent. Channel) North Cove Old) Saybrook and) Anchorage					197,710 + 42,600 240,310			
North Cove, Old Saybrook					306,265			
Anchorage - 6' + N. Cove					+ 334,425			
All of Old Saybrook					881,000			
Wethersfield Cove Ent. Channel						1,760		
Glastonbury (2 Piers)						46,110	19,211	

* Different contracts in the same year.

Table 4.3 (cont'd)

Army Corps of Engineers Dredging Records in the
Connecticut River Basin Estuary - Measured in Cubic Yards

	1959	1961	1962	1964	1965	1968	1970	1972 Current Estimat
Glastonbury								
Upper Bar						26,004	14,512	
Brockway Bar							17,937*	
Saybrook Shoal							11,728*	
Potash Bar							26,107	
Press Barn Bar								4,000
Claybanks Bar								7,000
Claybanks Upper Bar								7,000

*Different contracts in the same year.

inorganic materials and the introduction of other materials. For instance, data collected on the Millers River indicated that from 16 to 93 percent of the sediment load was organic material." The lower percentage probably occurring in the winter and spring months.

Due to the underlying geology and the limited sedimentation indicated, the importance of nutrient and sediment renewal for agricultural production is greatly reduced in the Connecticut River Basin. Although it is true that flooding has established the fertile flood plains in the Connecticut River Valley; these flood plains are the depositional remains for thousands of years of flooding. Heavy demands on the soil made by today's farming practices require more nutrients than are provided by sediment renewal during flooding. Sole reliance on flooding rather than fertilizers would not allow the farmers to remain competitive with other farmers. However, this reliance on fertilizers may also have adverse effects on water quality because of the nutrient rich runoff associated with its use.

Finally, the results indicating only minor amounts of siltation in the Connecticut River Basin are supported by the information gathered by the Water Resources Center at the University of Massachusetts at Amherst in the publication 28, "Formation on Public Policy on Issue of Out-of-Basin Diversion of Connecticut River Flood Waters to Boston Metropolitan Area."

Although evidence indicates a relatively minor amount of siltation in the Connecticut Basin as a whole, there are local instances where sedimentation has been severe enouth to cause serious economic losses to local residences. For example, the Gale River has had extreme sediment buildup during the last ten years. Evidence indicates that nearby long-term highway construction on I-93 with little erosion control has been a major contribution to the sediment buildup. The Farmington River is another example of a heavily silted stream. Like the Gale River, it has decreased in depth, eroded its banks and formed sand bars due to watershed erosion and development. The Farmington River illustrates the consequences of heavily developing or overdeveloping a watershed without significant planning or enforcement of erosion control practices.

Sedimentation and severe stream bank erosion due to the frequent fluctuations in storage pool elevations at the hydroelectric dams has been reported and is now the subject of a technical investigation.

If erosion and sedimentation are to be controlled, it is necessary to enact erosion and sedimentation ordinances which should be enforced at all construction sites. Sound agricultural and silvicultural practices should be encouraged in order to eliminate other places of erosion. In general, sedimentation becomes a nuisance when the erosion induced by man's activities reinforces the normal sediment load carried by the Connecticut River.

Sections 5 and 6 were requested by the evaluators of the original 1970 Comprehensive Plan for general information. The topics covered are not specifically directed to the Connecticut River. It was felt that the information in Section 5 was necessary in order to determine the ramifications involved with selecting a structural method of flood control if a desired water quality is to be maintained. Section 6 points out the effectiveness of a buffer strip when used in flood management. It was felt that both of these topics were deficient in the original comprehensive study and should be included in the supplemental study.

5.0 CHANGES IN WATER QUALITY AS A RESULT OF IMPOUNDMENT

5.1 Introduction

Water quality is directly affected by stream dynamics. In a fast moving stream the physical-chemical conditions are entirely different from those found in an impoundment or other receiving body of water. When a dam is placed on a stream, one can expect numerous changes in water quality caused by the induced changes in depth and energy regimes. Although the changes are gradual and often depend on many extrinsic factors, the conditions they might cause often involve further social and economic ramifications.

The increased depth and the decreased stream velocities that occur when a stream enters an impoundment catalyze most of the natural water quality transformations. If a dam is to be placed on a stream, certain considerations must be made in order to prevent any detrimental changes in water quality.

5.2 Thermal Stratification

Thermal stratification, which occurs in impoundments, is basically a layering of water based on temperature induced density differences. It is directly dependent upon climate and lake depth. In the late winter or early spring the impoundment water is cold, easily mixed by wind action, and has a uniform temperature from top to bottom. As the season advances and the atmospheric temperature becomes higher, both the inflowing tributary water and the surface water in the impoundment get warmer and warmer and become more resistant to mixing. Finally, the resistance to mixing becomes great enough to over-balance the ability of the wind to accomplish circulation to the bottom of the impoundment, and stable stratification is established. When the lake becomes stratified it is divided into three distinct layers; the epilimnion or zone of circulation, the metalimnion or thermocline, and the hypolimnion or zone of stagnation. The depth of the epilimnion is determined by the amount of penetrating solar radiation and the magnitude of the spring winds.

The epilimnion may be 5 to 50 feet deep depending on impoundment depth and other factors. The impoundment is mixed to this depth by wind-induced currents, and this layer has a uniform temperature. Below the epilimnion is the thermocline, which may be 5 to 20 feet deep. The thermocline is a stratum in which the temperature decreases rapidly as depth increases. A thermocline has been defined for convenience, though on a strictly arbitrary basis, as a stratum of water in which the temperature decreases 1°C or more in the depth of 1 meter or 0.55°F per foot. The decrease in temperature is accompanied by an increase in density, with a corresponding increase in resistance to mixing. In the hypolimnion the water is protected from the atmosphere by the overlying thermocline and epilimnion; therefore, very little increase in temperature occurs after stratification is established. Temperatures are low and quite uniform throughout the hypolimnion.

Summer stratification persists until the fall when the influent water becomes cooler. The cooler water is mixed throughout the epilimnion and the upper portions of the thermocline by convection and wind action. Cooling continues until the temperatures and densities of the epilimnion and thermocline approach those of the hypolimnion. When this is accomplished, resistance to mixing is diminished, and the fall overturn occurs.

In northern climates, winter stratification can occur because 0°C water is lighter than 4°C water. This density difference an anomolous property of water can produce thermal stratification although now the cooler water is the top water. The prevention of wind mixing because of ice cover maintains this stratification, if such a cover exists. Although the thermal cause and the chemical effect of thermal stratification have been adequately studied and reported, the effect of physical factors and the environment on the presence or absence of thermal stratification has received little attention.

Previous research has not enumerated which environmental factors tend to enhance or inhibit thermal stratification. This situation must be remedied if the site of a planned impoundment is to be evaluated on the basis of its thermal stratification potential. Future investigations hope to show how various external factors relate to thermal stratification. Some of the factors to be investigated are: (1) general soil characteristics, (2) annual rainfall, (3) average precipitation from April through September, (4) prevailing wind directions, (5) average wind velocity, (6) land cover of surrounding area, (7) time of last frost in spring, (8) time of earliest frost in fall, (9) shape, (10) size, (11) depth, (12) orientation of impoundment, (13) inflow pattern, and (14) weather during the period of the onset of stratification. The correlation of these factors through the use of a discriminate function, to the presence or absence of thermal stratification in existing impoundments will reveal which factors have the major influence on thermal stratification.

Thermal stratification directly influences other physical parameters in an impoundment. A primary effect is exhibited in the dissolved oxygen profile of a water body. This is explained by the fact that trophogenic activity coincides with the epilimnion since this is usually the zone of effective light penetration and tropholytic activity coincides with the hypolimnion. Since the hypolimnion is cut off from air in the absence of mixing, it soon becomes depleted of dissolved oxygen as a result of respiration by the tropholytic organisms. As primary productivity increases in the trophogenic zone, more decomposition will be necessary when these organisms die and sink into the tropholytic zone. Since there is no photosynthetic activity in the hypolimnion due to the absence of light, there is no oxygen production. Hence, the dissolved oxygen in the layer may go to zero and heterotrophic activity may become seriously reduced, which will in turn reduce the CO_2 return through respiration.

Thus, thermal stratification can induce two fairly distinct environments, one aerobic and the other generally anaerobic. These are usually integrated only at the time of overturn.

5.3 Settling Basin Effect

Another feature inherent to lakes and impoundments is their ability to act as a settling basin. In streams, material is continuously transported downstream until the stream enters a lake or impoundment. Here the material accumulates in the basin and becomes concentrated.

The settling basin phenomena in conjunction with thermal stratification accounts for most of the physical-chemical changes in water quality that occur when a stream enters an impoundment. The effects of these phenomenon are felt in most of the features discussed below.

5.4 Eutrophication

Eutrophication or nutrient enrichment is a problem inherent to both lakes and streams. Because of the collecting nature of a lake or impoundment and thermal stratification, nutrients released from domestic wastes are transported by the streams and concentrated in the receiving waters. The nutrients are circulated to the euphotic zone during times of overturn and enhance algal growth. The primary nutrients felt to be responsible for nuisance algal growths are: nitrogen, phosphorus and to some extent, organic carbon.

Algal blooms have been responsible for fish kills, due to either supersaturation of oxygen, or depletion of oxygen. The supersaturation is caused by excessive oxygen production by photosynthesis and generally occurs only in the epilimnion, while the depletion is caused by the oxidative processes involved in the decomposition of dead algae in the hypolimnion.

In addition to fishing impairment, bathing, boating and water skiing are often indefinitely postponed in waters which would otherwise offer maximum multiple recreational use. Industrial and municipal water treatment is hampered and made ineffective by extensive aquatic growth; taste and odor problems appear, and property values and resort trade often suffer as a result of intense algal blooms. Accelerated decomposition of dense algal scums, associated organisms, and debris encourages odor and hydrogen sulfide gas, which creates strong citizen protest and often stains the white paint on nearby buildings.

Eutrophication is primarily a man-induced problem. In areas where proposed impoundments will receive no agricultural or domestic runoff or discharges from either nearby or upstream sources, eutrophication will be of minor importance. Sound silvicultural practices must also be maintained since research has shown that nitrogen concentrations in receiving waters sharply increase when uncontrolled deforestation occurs.

However, impoundments which serve recreational interests often encourage the establishment of nearby summer camps. These camps often have poorly constructed overcrowded septic systems which lead to nutrient influx into the lake. Also, associated with these summer developments are poorly maintained roads and cleared areas which are subject to erosion and lead to increases in sediment influx. These sediments cause ecological hardships on the receiving water's organisms.

If recreational interests are planned for any proposed impoundment then more stringent zoning laws and land use planning should be mandatory. A thorough investigation of the physical features around an impoundment should be made to determine an environmentally safe development potential and the costs for these investigations should be figured in the benefit cost ratio of the proposed project.

5.5 Light Penetration and Turbidity Removal

Research has shown that there is a direct relationship between light intensities and photosynthetic rates. The induced turbidity caused by a stream's current action is eliminated when the stream enters into the lower energy regime of an impoundment. The reduction of turbidity and the accompanied increased penetration of light caused by particulate settlement and extended detention periods leads to increased primary productivity.

However, the decreased turbidity can be short-lived, because ironically turbidity can also be a result of primary productivity. As the productivity increases so does the turbidity resulting in a migration of algae to the surface. If algae cannot get the required light for growth at depth, migration to the surface occurs resulting in the development of algal mats. Algal mats block further light penetration and thereby decrease photosynthesis. By decreasing photosynthesis, there is a decreased oxygen supply leading to a transition from game to rough fish and eventually possibly leading to complete eutrophic conditions. Decreased dissolved oxygen, usually accompanied by an increase in turbidity favors the formation of sludge deposits. As dissolved oxygen decreases, the bottom turns anaerobic and results in a chemical change going to toxic levels. pH changes in extremes toward acidity and alkalinity and the temperature increases. The net result being tainted fish flesh and nutrient production favoring undesirable aquatic growths.

The process described above usually takes thousands of years to occur unless there are other induced factors such as waste discharges and agricultural runoff. The point to be made is one of awareness; that this would happen if checks weren't taken to prevent it.

5.6 Oxygen Production and Demand

When dealing with an impoundment, the net effect of the algal population on the oxygen balance becomes important. One must consider not only oxygen production by the algae, but also organism respiration. Another factor often overlooked in oxygen production and demand is the amount atmospheric reaeration supports photosynthetic oxygen production.

In some instances photosynthetic activity is so vigorous that the upper layers become supersaturated, and oxygen is lost to the atmosphere. In many instances it would be wise to mechanically mix these saturated layers with lower ones in order to satisfy oxygen demands in these parts of the impoundments. Algal population and other populations exert three forms of oxygen demand on a water body:

1. Respiration that occurs while photosynthesis is progressing,
2. Respiration that occurs at night when photosynthesis is absent, and
3. The oxygen uptake caused by consumer organisms, mainly bacteria, that metabolize the algal bodies upon their death.

Studies show that the net 24-hour contribution to the oxygen balance would be near zero, if all of the algae stayed in the upper layers of water. Because many algae fall from the euphotic zone during a given 24-hour period, the dark respiration, and/or the oxygen uptake because of bacterial decomposition, do not occur in the surface waters. The net increase in oxygen concentration due to algal action is generally in the surface waters, while the major portion of the oxygen demand takes place in the bottom waters or bottom sediments.

Hence, although algae may produce a net increase in dissolved oxygen concentration in surface waters, their decomposition in deeper waters, with a corresponding oxygen uptake, means that the net gain in the oxygen resources of the impoundment is reduced or possibly even deficient.

There are conflicting viewpoints concerning the effect of impoundments on stream purification. Some studies indicate that a more intense rate of deoxygenation can occur in impoundments while the rate of reoxygenation is the same as that occuring in a free flowing river. In some instances, self-purification has been improved by an impoundment due to the reduced speed of the flow and increased surface area of the water body.

The data from other investigations suggest that reoxygenation in impoundments depends upon diffusion into the surface layer from the atmosphere and from the process of photosynthesis. The amount of diffusion from the surface layer would be dependent upon wind action and density induced currents in the case of atmospheric diffusion and the penetration of sunlight in the case of photosynthesis. Due to the limited mixing created by wind action and density currents only photosynthetic oxygen concentration might increase in the impoundments.

Decreasing water velocity does allow settling of formerly suspended solids which explains why BOD, phosphates and coliforms are frequently reduced after an impoundment. Dissolved solids and the BOD attributed to dissolved solids are not decreased as rapidly in impoundments as in the free flowing stream.

Based upon these views, the establishment of an impoundment alone may not necessarily induce water quality degradation. Other factors such as effluent discharges, runoff, and land use combine to create water quality problems which usually occur in conjunction with the establishment of an impoundment.

5.7 Carbonate Equilibrium

Since algae remove carbon dioxide from solution as they grow and convert it into cellular material, the carbonate equilibrium as it exists in natural waters is affected. This is especially true in impoundments or other standing water bodies where algae is usually more prolific. When CO_2 is removed the net result through the carbonate equilibria is an increase in pH considerably above 7. A ceiling on pH is formed by precipitation of calcium carbonate that controls the amount of carbonate ion that can coexist in solution with calcium ion. There have been observed pH values as high as 9.8 where algae are in high concentration and under favorable light conditions.

In deeper impoundments where stratification occurs, the transformation of bicarbonate to carbonate ions occurs in the upper layers of the water, but the precipitated carbonate particules dropping down into the hypolimnion may or may not reach the bottom. This is because the hypolimnion generally contains relatively higher concentrations of carbon dioxide due to the biological activity that has occurred in these waters during the decomposition of falling algal bodies and because of the absence of many viable algae in the hypolimnion. The precipitated carbonate particles combine with this carbon dioxide and are converted into soluble bicarbonates that increase the alkalinity of the deeper waters. Carbonate precipitation is common in standing bodies of water and has been responsible for commercially important marl deposits in natural lakes.

Research in this area is important, since changes in the carbonate equilibrium can cause either the precipitation of hardness causing ions, the reduction of alkalinity, or under reverse conditions the dissolution of carbonates from the impoundment bed.

5.8 Iron and Manganese

Iron and manganese often pose serious staining problems in water supplies. Both iron and manganese are insoluble in their oxidized form. For this reason they often pose no serious problem in streams and impoundments which have a sufficient dissolved oxygen concentration throughout. However, in deeper stratified impoundments where the dissolved oxygen concentration is often depleted in the hypolimnion, the iron and manganese occur in the soluble reduced forms. Thus, instead of precipitating out as they would in their oxidized forms, they remain suspended in their soluble reduced forms.

5.9 Artificial Destratification of Impoundments

Most authorities agree that the prevention of the deterioration of the hypolimnion and its water quality through impoundment destratification would be beneficial. Mixing would prevent many of the changes that occur in water quality in deep impoundments, such as: (1) low dissolved oxygen concentrations; (2) increased iron and manganese concentrations, (3) production of hydrogen sulfide that occurs when organic matter decomposes in the deoxygenated hypolimnion of deep stratified impoundments, and (4) increase in color in the hypolimnion such as the yellow coloring matter of "humic matter." However, mixing would also prevent the accumulation of cool waters in the impoundment bottom and might increase overall productivity by recycling back into the euphotic zone nutrients released during organic decomposition. If the impoundment prevents the removal of bottom sediments which exert an oxygen demand on the stream, then some means of physical destratification and reaeration would probably be necessary for the maintenance of water quality.

Some studies have shown that reaeration has effectively precipitated or coagulated nutrients from the water body and that this oxidized material along with the oxidized and precipitated iron, magnesium, and other materials has formed an effective seal over nutrient rich bottom sediments, thus effectively preventing nutrient return to the epilimnion during times of overturn.

5.10 Thermal Pollution

The addition of warm water to an impoundment, either due to the warming of the influent waters because of solar radiation or due to the discharge of warmed cooling water from industrial processes, influences the water quality in impoundments. These warm waters tend to stay near the surface of the impoundment. This warm water influences aquatic life in the surface waters of the impoundment, influences the rate of deoxygenation from biological degradation of organic matter by speeding the process and influences dissolved oxygen concentrations because of decreased oxygen solubility in higher temperature water. The latter reduces the surface deficit, and thereby reduces the reaeration rate.

Another thermal pollution problem is the release of cold hypolimnetic water to warmer downstream water. If the temperature change is great, the stress placed on downstream aquatic life will be considerable. Thus, water control structures can have a profound influence on temperature and, if designed and used properly, can promote desirable downstream conditions while avoiding undesirable ones. This reemphasizes the need to understand the influences caused by the design and operation of outlet works.

5.11 Influence of Impoundment Releases on Downstream Water Quality

Most investigations are concerned with the degradation of downstream water quality because of releases of poor quality water from impoundments. Evidence shows that there are downstream stresses caused by the discharge of water with a low dissolved oxygen concentration and a high manganese concentration during peaking power operations. This situation could also result from hypolimnion releases from deep reservoirs. Although water with a low dissolved oxygen concentration reaerates rapidly because of the high oxygen deficit, there are problems with downstream water treatment because of manganese concentrations, and there is difficulty in using the streams for the assimilation of organic wastes. In some cases there have been reports of the absence of fish life due to too much of an oxygen deficit.

Because of different temperatures and chemical compositions, hypolimnion releases must be considered very carefully. The various chemical and physical changes in these waters as opposed to the downstream receiving water could cause radical alterations in the plant and animal life.

The following are six effects that should be investigated in the establishment of any deep water impoundment if the complete effect of a streamflow regulation scheme is to be assessed:

1. The influence of dilution on the rate of biological deoxygenation, must be investigated. The dilution of a given polluted stream may cause an increase or decrease in the rate of biological oxidation of the organic matter in that stream.

2. Because of increased turbulence and increased depth caused by increased flow, the rate of reaeration may be changed in a given situation when dilution water is added.

3. Because of increased flow, the time of travel between a source of pollution and a possible water use will be shortened. In certain situations, poorer quality water may arrive at a downstream point because this decreased time of travel would decrease the opportunity for natural purification to occur.

4. If algal toxins are present in the river and these toxins are preventing an undesirable bloom of algae, the dilution of this water with toxin-free water from an impoundment may well result in undesirable effects.

5. The discharge of good chemical quality, but low temperature, water may interfere with downstream recreational facilities or the type of fish present. Cold water released may also upset spawning and other reproductive cycles.

6. The absence of fish life below some dams discharging hypolimnion water, even though it has been reaerated, has led to the supposition that in the reducing environment of the hypolimnion, substances toxic to aquatic life are produced. If this possibility is true, it must be investigated since even on reaeration, this water may be undesirable as dilution water*.

The effects on downstream water users generated from the effects of impoundments include increased treatment costs at points of withdrawal for water supply use. Taste and odor, color, iron and manganese concentrations all may be increased above previous stream concentrations and require treatment for removal. Inorganic nutrients, principally phosphorus and ammonia-nitrogen may be present in increased amounts if the reservoir hypolimnion was anaerobic. These nutrients can stimulate rooted aquatic plant growth as well as plankton growth in downstream reaches. Plankton in nuisance amounts can produce water treatment problems by contributing taste and odor to water and by interfering with filtration processes. Both plankton and rooted aquatics reduce the aesthetic quality of water, reduce recreational appeal and pose subsequent oxygen demands on the stream's dissolved oxygen resources.

Two final considerations to be recognized concerning downstream releases are the possibility of increased bottom scour and subsequent increased erosion and sedimentation and the maintenance of diffusion and natural mixing of downstream water. If dilution water becomes channeled and does not mix with the entire contents of a river, the entire benefit of this water will not be realized. This problem would be accentuated in wide, relatively slow-moving rivers where waste inputs as well as dillution water might cling to one shore or the other and might be very slowly blended.

5.12 Effects on Groundwater

The most important effect of a dam on groundwater quality occurs where the foundation of the structure provides a substantial or complete cutoff of groundwater flow in an aquifer. Such a stoppage reduces the hydraulic gradient of the groundwater upstream of the dam. This causes an increased accumulation of pollutants in the groundwater because of slower movement or complete stoppage.

---

* Number 5 in Bibliography

Another effect is caused by the higher water table created back of a dam which extends around the periphery of the reservoir. The high water table brings the groundwater closer to the ground's surface where the opportunity for pollution from surface pollution sources may be increased. Marshy area, swamps, and pools also may be created.

Even in situations where the dam and its foundations do not substantially alter the total groundwater flow through the underlying aquifers, the localized effects on groundwater levels and on the original pattern of groundwater flow may have significant adverse impacts on groundwater quality. Seepage losses from the reservoir also contribute to the groundwater. If the quality of the water in the reservoir is better than that of the groundwater, improvement in groundwater quality results. Conversely, seepage losses from a reservoir storing poorer quality water (e.g., reclaimed water) degrade the groundwater.

5.13 Watershed Development

In certain areas, development of land areas tributary to reservoirs may constitute major sources of pollution and nutrient fertilization. On small reservoirs constructed in conjunction with suburban housing developments direct drainage from streets and lawns constitutes the primary cause of water quality degradation. On large reservoirs increases in upstream tributary population and development on the periphery of the lake shore must be considered in projecting water quality although these sources may not be of immediate concern.

Suburban development surrounding a small reservoir can deteriorate water quality by direct waste disposal through the use of sewage treatment plants not providing nutrient removal, discharges from watercraft, runoff from yards and streets and by infiltration from polluted groundwater where septic tanks are used. Contamination in the feeding stream upstream from the reservoir intensifies the pollution problem.

Larger reservoirs are also adversely affected by direct sources but because of the volume of dilution available, these effects may not be immediately noticeable. Large direct discharges from industries or municipalities, however, can seriously degrade water quality unless adequate treatment is provided for these sources. Nutrient concentrations from upstream point and non-point sources may accelerate eutrophication processes, causing algal blooms and subsequent dissolved oxygen deficits.

Unfortunately, flood control reservoirs encourage more development downstream by providing a sense of security to investment concerns. This increased development provides more wastes and waste loads for the downstream segments of the stream.

5.14 Remarks

Although most of the above situations only occur in deep water reservoirs, some are applicable to shallow reservoirs.

The situations discussed are not inevitable, but can be controlled to a very large degree. The purpose of these remarks was to create an awareness so that effective planning at the impoundment site and upstream and downstream from the impoundment could be exercised so as to prevent or control these situations.

5.15 Bibliography Dealing With the Effects of Impoundments on Water Quality

I. General information

1. ________, "Symposium on Streamflow Regulation For Quality Control," Environmental Health Series Supply and Pollution Control, U.S. Department, Education and Welfare, Public Health Service. Publication No. 999-WP-30.

2. Duffer, William R., and Harlen, Curtis C. Jr., Changes in Water Quality Resulting From Impoundment, Office of Research and Monitoring, Environmental Protection Agency. Project No. 16080 GGH, August 1971.

3. Frey, David G., ed Limnology in North America, University of Wisconsin Press, Madison 1963, p. 461

3A Hynes, H.B., The Biology of Polluted Waters, Liverpool University Press, 1960.

4. Ruttner, Franz, Fundamentals of Limnology, University of Toronto Press, third edition, 1971.

5. Symons, James M., ed, Water Quality Behavior in Reservoirs, U.S. Department of Health, Education and Welfare, Public Health Service and Environmental Health Service, Environmental Control Administration, Public Health Service Publication No. 1930.

II. Behavior of water quality in impoundments

A. Measurements of water quality in impoundments

6. Churchill, M.A. Effects of storage impoundments on water quality. J. Sanit. Eng. Div. Proc. ASCE. 83 (SAL:Paper 1171. Feb. 1957, 48 pp.).

7. Cleary, E.J. An electronic monitor system for river-quality surveillance and research. Intern. J. Air Water Pollution. 7:331-42. 1963. Also in: Advances in water pollution research, Proc. 1st Intern. Conf. Vol. 1. Pergamon Press, London, U.K., 1964. pp-63-73.

8. Kneese, A.V. Water Pollution-economic aspects and research needs. Resources for the Future, Inc., Wash., D.C., 1962. 107 pp.

9. Love, S.K. Relationship of impoundments to water quality. JAWWA. 53:559-68. May 1961.

10. McCallum, G.E. and H. Stierlie, How automation plays a part in water-quality surveillance. Water Works and Wastes Eng. 1:68-70. May 1964.

11. Mentink, A.F. Instrumentation in water quality. Paper 153 presented at Water Resources Conf. ASCE, Mobile, Ala., March 1965.

12. Monitor system continuously records river water quality Chem. Eng. News. 41:54-56. May 6, 1963.

13. Neel, J.K., H.P. Nicholson and A. Hirsch. Main stem reservoir effects on water quality in the central Missouri River, 1952-1957, USDEH. PHS. Region VI, Water Supply and Pollution Control, Kansas City, Mo. March 1963. 111 pp.

14. Ragone, S., and B.J. Peters. Water Quality monitoring for water quality control. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanitary Engr. Center, Cincinnati, Ohio, April 3-5, 1963. PHS. Publ. No. 999-WP-30. June 1965. pp. 345-65.

15. Samworth, R.B., and J.A. Defilippi. Final report on an investigation of low-flow augmentation for stream-pollution abatement. Div. Water Supply and Pollution Control.

16. Res. and Trng. br., USPHS, Grant No. Wp-00153. (Project title: Low-flow augmentation for stream-pollution abatement. (Johns Hopkins Univ. Baltimore, Md. Sept. 1963. 37 pp. Appendices.

17. Stearns, F.P. Effect on storage upon the quality of water. J. New Engl. Waters Works Assoc. 5:115-1890-91.

18. Water Resources activities in the United States. Water supply and demand. Senate Select Committee Print No. 32. U.S. Gov't Printing Office, Washington, D.C. 1960.

19. Weibel, S.R., R.J. Anderson, and R.L. Woodward. Urban land runoff as a factor in stream pollution. JWPCF. 36:914-24, July 1964.

B. Eutrophication

20. Algae and metropolitan wastes. Trans. of seminar, Cincinnati, Ohio, Apr. 27-29, 1960. Tech. Rep. W61-3. Robert A. Taft Sanit. Eng. Center. 1961. 162 pp.

21. Antia, N.J., C.D. McAllister, T.R. Parsons, K. Stephens, and J.D.H. Strickland. Further measurements of primary production using a large-volume plastic sphere. Limnol. and Oceanog. 8:166-83. Apr. 1963.

22. Bensing, W. Lake Constance: Maintenance of its quality and navigation in the Rhine Wasserwirtschaft (Stuttgart). 50:238-43. 1960. Water Pollution Abstr. 35:Abstr. No. 777. Apr. 1962.

23. Borchardt, J.A., "Eutrophication-Causes and Effects," Journal American Water Works Association Vol. 61, No. 6, June 1969, pp. 272-275.

24. Cox, George W., ed. *Readings in Conservation Ecology*, Meredith Corporation 1969; Chapter 31, "Eutrophication of the St. Lawrence Great Lakes," pp. 473-492 - Alfred M. Beeton, and Chapter 32, "Control of Eutrophication," pp. 493-503, R.T. Edmondson.

25. Fruh, E. Gus, Kenton M. Stewart, G. Fred Lee, and Gerard A. Rohlich, "Measurements of Eutrophication and Trends," Journal Water Pollution Control Federation, August 1966, Vol. 38 pp. 1237-1258.

26. Fruh, E. Gus, "The Overall Picture of Eutrophication," Journal Water Pollution Control Federation, September 1967, Vol. 39, pp. 1449-1463.

27. Gerloff, G., and F. Skoog, Nitrogen as a limiting factor for the growth of Microcustis aeruginosa in southern Wisconsin lakes. Ecology. 38:556-61. Oct. 1957.

28. Goldman, C. R.,A method of studying nutrient limiting factors in situ in water columns isolated by polyethylene film. Limnol. and Oceanog. 7:99-101. Jan. 1962.

29. Goldman, C.R., A rapid field technique for determining micronutrient limiting factors in fresh water and notes on the use of gas phase in calibration of C^{14} productivity experiments. In: Symposium on new methods of determining biogenic and organic substances in water and organisms. Hydrobiol. Lab. Czechoslovak Acad. Sci, Prague, Czech., Sept. 30-Oct. 1, 1963. 1 p.

30. Grundy, Richard D., "Strategies for Control of Man-Made Eutrophication," Environmental Science and Technology, Dec. 1971, pp. 1184-1190.

31. Hasler, A. D., Eutrophication of lakes by domestic drainage. Ecology. 28:383-95. Oct. 1947.

32. Hutchinson, G. E., A treatise on limnology. Vol. 1. Geography, physics, and chemistry. John Wiley and Sons, Inc. New York, N. Y., 1957. 1015 pp.

33. Laurent, P., What do we know of the actual condition of Lake Geneva? Föderation Europäischer Gewässerschutz Informations blatt, No. 4, pp. 11- . 1960. Water Pollution Abstr. 35: Abstr. No. 1108. June 1962.

34. Mackenthun, K. M., The effects of nutrients on photosynthetic oxygen production in lakes and reservoirs. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanit. Engr. Center, Cincinnati, Ohio, Apr. 3-5, 1963. PHS Publ. No. 999-WP-30. June 1965. pp. 205-15.

35. McGauhey, P. H., R. Eliassen, G.A. Rohlich, H.F. Ludwig, and E.A. Pearson, Comprehensive study on protection of water resources of Lake Tahoe Basin through controlled waste disposal. Report prepared for Lake Tahoe Area Council by Engineering-Sciences, Inc. June 1963. 157 pp.

36. Oswald, William J. and C.G. Golucke, "Eutrophication Trends in the United States - A Problem?", Journal Water Pollution Control Federation, June 1966, Vol. 38, pp. 964-975.

37. Rodhe, W. Environmental requirements of fresh water plankton algae. Symbolae Botan. Upsalienses. 10:1-149. 1948.

38. Safferman, R.S., and M.E. Morris. Control of algae with viruses. JAWWA. 56:1217-24. Sept. 1964.

39. Sawyer, Clair N., "Basic Concepts of Eutrophication", Journal Water Pollution Control Federation, Vol. 38, May 1966, No. 5, pp. 737-744.

40. Sawyer, C.N. Fertilization of lakes by agricultural and urban drainage. J. New Engl. Water Works Assoc. 56:109-27. June 1947.

41. Strickland, J.D. H. Measuring the production of marine phytoplankton. Bull. No. 122. Fisheries Research Board Can. 1960. 172 pp.

42. Stumm, W., and J.J. Morgan. Stream pollution by algal nutrients. In: Trans. 12th Ann. Conf. Sanit. Eng., Univ. Kansas, Manhattan, Kan., 1962. pp. 16-26.

C. Light penetration and turbidity removal

43. Dvihally-Tamas, S. Transformation of energy in inland waters examined on the basis of investigations carried out using modern physico-chemical methods. Intern. Ver. Theoret. Angew. Limnol., Verhand. 14:99-103. 1961.

44. Little, J.A. Pearl River shallow water reservoir water quality-recreation project. USDHEW, PHS, Region IV. Atlanta, Ga., Mar. 1963. 50 pp. Appendices.

45. Metzler, D.F. Improvement of water quality in Kansas. JAWWA. 50:1180-84. Sept. 1958.

46. Vaccaro, R.F., and J.H. Ryther. The bactericidal effects of sunlight in relation to "light" and "dark" bottle photosynthesis experiments. J. Conseil, Conseil permanent intern. exploration mer. 20:18-24. 1954.

47. Varma, M.M., and M.J. Wilcomb. Effect of light intensity on photosynthesis. Water and Sewage Works, 110:426-29. Dec. 1963.

48. Verduin, J. Discussion of "Photosynthesis as a factor in the oxygen balance of reservoirs," by C.H.J. Hull. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanit. Eng. Center, Cincinnati, Ohio, Apr. 3-5, 1963. PHS Publ. No. 999-WP-30. June 1965. pp. 91-94.

D. Oxygen production and demands

49. Edmondson, W.T. Secondary production and decomposition. Intern. Ver. Theoret. Angew. Limnol. Verhand. 14:316-39. 1961.

50. Fish, F.F., C.H.J. Hull, B.J. Peters, and W.E. Knight. A study of the effects of a submerged weir in the Roanoke Rapids Reservoir upon downstream water quality. Spec. Rept. No. 1. Compiled by Special Report Committee, Roanoke River Studies, Raleigh, N.C. Feb. 6, 1958. Unpublished report. 63 pp. Appendices.

51. Hull, C.H.J. Oxygenation of Baltimore Harbor by planktonic algae. JWPCF. 35:587-606. May 1963.

52. Hull, C.H.J. Discussion of "Oxygen balance of an estuary," by D.J. O'Connor. J. Sanit. Eng. Div. Proc. ASCE 86(SA6):105-20. Nov 1960.

53. Hull, C.H.J. Photosynthesis as a factor in the oxygen balance of reservoirs. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanit. Eng. Center, Cincinnati, Ohio, Apr. 3-5, 1963. PHS Publ. No. 99-WP-30. June 1965. pp. 77-91.

54. Hull, C.H.J. Photosynthetic oxygenation of a polluted estuary. Intern. J. Air Water Pollution. 7:669-96. Aug. 1963. Also in: Advances in water pollution research, Proc. 1st Inter. Conf. Col. 3. Pergamon Press. London, U.K., 1964. pp. 347-74.

55. Kaplovsky, A.J. Discussion of "Photosynthetic oxygenation of a polluted estuary," by C. H. J. Hull. In: Advances in water pollution research, Proc. 1st Intern. Conf. Vol. 3. Pergamon Press, London, U.K., 1964. pp. 374-403.

56. Knopp, H. The influence of plankton on the oxygen demand of river water. Deut. Gewasserkundliche Mitt. 3:65-70. 1959. Water Pollution Abstr. 33:Abstr. No. 1765. Oct. 1960.

57. Odum, H.T. Primary production in flowing waters. Limnol. and Oceanog. 1:102-17. Apr. 1956.

58. O'Connell, R.L., N.E. Thomas, P.J. Godsil, and C.R. Hirth. Report of survey of the Truckee River. Robert A. Taft Sanit. Eng. Center, Div. Water Supply and Pollution Control Aug. 1963. Mimeo. 45 pp.

59. Pratt, D.M., and H. Berkson. Two sources of error in the oxygen "light" and "dark" bottle method. Limnol. and Oceanog. 4:328-34. July 1959.

60. Thomas, N.A. Oxygen deficit rates for the central basin of Lake Erie. Proc. 6th Conf. on Great Lakes Research, Ann Arbor, Mich., June 13-15, 1963. Publ. No. 10. Great Lakes Research Div., Univ. Michigan. Abstract, p. 133.

61. Towne, W.W., A.F. Bartsch, and W.H. Davis. Raw sewage stabilization ponds in the Dakotas. Sewage and Ind. Wastes. 29:377-96. Apr. 1957.

62. Verduin, J. Energy fixation and utilization by natural communities in western Lake Erie. Ecology. 37:40-50. Jan. 1965.

63. Verduin, J. Photosynthesis by aquatic communities in northwestern Ohio. Ecology. 40:377-83. July 1959.

E. Carbonate equilibrium

64. Sawyer, C.N. Chemistry for sanitary engineers. McGraw-Hill Book Co., Inc., New York, N.Y., 1960. 367 pp.

65. Weber, W.J., Jr., and W. Stumm. Mechanism of hydrogen ion buffering in natural waters. JAWWA. 55:1553-78. Dec. 1963.

F. Nutrient removal

66. Gates, W.E., and J.A. Borchardt. Nitrogen and phosphorus extraction from domestic wastewater treatment plant effluents by controlled algal culture. JWPCF. 36:443-62. Apr. 1964.

67. Hicks, R. Interim report on results of research into methods of harvesting and possible utilization of algae cultivated in experimental sewage oxidation ponds at the Omaru Creek Pilot Plant of the Auckland Metropolitan Drainage Board. 1958. Water Pollution Abstr. 32:Abstr. No. 1678. Sept. 1959.

68. King, Darrell L., "The Role of Carbon in Eutrophication", Journal Water Pollution Control Federation, Vol. 42, No. 12, pp. 2035-2051.

69. Liebig, J. Chemistry and its application to agriculture and physiology. 4th ed. Taylor and Walton, London, U.K., 1847. pp. 20, 198, 205, 224.

70. McGriff, E. Corbin, Jr., and Ross E. McKinney, "Activated Algae: A Nutrient Removal Process", Water and Sewage Works, November 1971, pp. 377-379.

71. Oswald, W.J. The coming industry of controlled photosynthesis. Amer. J. Public Health. 52:235-42. Feb. 1962.

72. Sawyer, Clair N., "Basic Concepts of Eutrophication", Journal Water Pollution Control Federation, March 1968, Part 1, pp. 363-370.

G. Dissolved oxygen

73. Birge, E.A., and O. Juday. The inland lakes of Wisconsin. Wis. Geol. Nat. Hist. Surv. Bull. No. 22 1911. 259 pp.

74. Bueltman, C., J. Termini, and W. Kingsbury. Power requirements for oxygen transfer with turbine aerators. Intern. J. Air Water Pollution. 5:175-79. May 1963. Also in: Advances in biological waste treatment. Eckenfelder and McCabe, Eds. Pergamon Press, London, U.K., 1963. pp. 175-79

75. Churchill, M.A., H.L. Elmore, and R.A. Buckingham. The prediction of stream reaeration rates. J. Sanit. Eng. Div., Proc. ASCE. 88(SA4): 1-46. July 1962. Also in: Advances in water pollution research, Proc. 1st Intern. Conf. Vol. 1 Pergamon Press, London, U.K., 1964. pp. 89-126.

76. Fair, G.M. The DO sag - an analysis. Sewage Works J. 11:445-61 May 1939.

77. Fremling, C.R., and J.J. Evans. A method for determining the the dissolved oxygen concentration near the mud-water interface. Limnol. and Oceanog. 8:363-64. July 1963.

78. Hull, C.H.J. Second progress report of an investigation of low-flow augmentation for stream-pollution abatement.

79. Report No. XII. Div. Water Supply and Pollution Control, Res. and Trng. Br., USPHS, Grant No. WP-00153. (Project title: Low-flow augmentation for stream-pollution abatement.) John Hopkins U., Baltimore, Md., Oct. 1961.

80. Hull, C.H.J. Simplified technique for determination of theoretical and effective self-purification coefficients of polluted streams. Report No. III of the low-flow augmentation for stream-pollution abatement project. Div. Water Supply and Pollution Control, Res. and Trng. Br., Br. USPHS, Grant No. WP-00153. (Project title: Low-flow augmentation for stream-pollution abatement.) Johns Hopkins U., Baltimore, Md. 1960. 90 pp.

81. Ingols, R.S. Effect of impoundment on downstream water quality, Catawba River, S.C. JAWWA. 51:42-46. Jan. 1959.

82. Ingols, R.S. Pollutional effects of hydraulic power generation. Sewage and Ind. Wastes 29:292-97. Mar. 1957.

83. Kittrell, F.W. Effects of impoundments on dissolved oxygen resources. Sewage and Ind. Wastes. 31:1065-78. Sept. 1959.

84. Krenkel, P.A. and G.T. Orlob. Turbulent diffusion and the reaeration coefficient. J. Sanit. Eng. Div., Proc. ASCE. 88(SA2): 53-82. Mar. 1962.

85. O'Connor, D.J., and W.E. Dobbins, The mechanism of reaeration in natural streams. J. Sanit. Eng. Div., Proc. ASCE. 82(SA6): Paper 1115. Dec. 1956. 30 pp.

86. Olszewski, P. Experiment on drawing off the hypolimnic water from a lake, results of the first experimental year. Intern. Ver. Theoret. Agnew. Limnol., Verhan. 14:855-61. 1959. Water Pollution Abstr. 35:Abstr. No. 1569. Aug. 1962.

87. Oxygen relationships in streams. Proc. of seminar, Cincinnati, Ohio, Oct. 30-Nov. 1, 1957. Tech. Rep. W58-2. Robert A. Taft Sanit. Eng. Center. Mar. 1958. 194 pp.

88. Phelps, E.B. The biochemistry of sewage. 8th Intern. Congr. Appl. Chem. 26:251-60. 1912.

89. Scott, R.H., T.F. Wisniewski, B.F. Lueck, and A.J. Wiley. Aeration of stream flow at power turbines. Sewage and Ind. Wastes. 30:1496-1505. Dec. 1958.

90. Streeter, H.W., and E.B. Phelps. A study of the pollution and natural purification of the Ohio River. III. Factors concerned in the phenomena of oxidation and reaerations. PHS Bull. No. 146. Feb. 1925. 75 pp.

91. Winberg, G.G., and T.N. Sivko. The significance of photo-aeration in the oxygen balance of polluted waters. Intern. J. Air Water Pollution. 6:267-75. May-Aug. 1962.

H. Nitrogen

92. Cooper, G.S., and R.L. Smith. Sequence of products formed during denitrification in some diverse western soils. Proc. Soil Sci. Soc. Amer. 27:659-62. 1963.

93. Courchaine, R.J. The significance of nitrification in streams analysis-effects on the oxygen balance. In: Proc. 18th Ind. Waste Conf., Lafayette, Ind., Apr. 30-May 2, 1963. Eng. Ext. Ser. No. 115. Eng. Bull., Purdue U. 48 (3) : 38-50. May 1964.

94. Johnson, W.K., and G.J. Schroepfer. Nitrogen removal by nitrification and denitrification. JWPCF. 36:1015-36. Aug. 1964.

95. Kaylor, F.B., M.H. Bechir, and J.M. Symons. Atmospheric nitrogen fixation in activated sludge. In: Proc. 18th Ind. Waste Conf., Lafayette, Ind., Apr. 30-May 2, 1963. Eng. Ext. Ser. No. 115. Eng. Bull., Purdue Univ. 48(3):243-63. May 1964.

96. Leclerc, E. Self-purification of fresh water streams as affected by temperature and by the content of oxygen, nitrogen and other substances. Intern. J. Air Water Pollution. 7:357-65. June 1963. Also in: Advances in water pollution research, Proc. 1st Inter. Conf. Vol. 1. Pergamon Press, London, U.K. 1964. pp. 51-62.

97. Schmidt, B., and W.D. Kampf. Alteration of the nitrogen balance in liquid nutrients by some bacteria occurring in surface waters. Z. Hyg. Infektionskrankh. 147:495-503. 1961. Water Pollution Abstr. 35:Abstr. No. 439. Mar. 1962.

98. Symons. J.M., and R. Labonte. A procedure for continuous nitrification corrections during Warburg respirometer studies. In: Proc. 18th Ind. Waste Conf., Lafayette, Ind., Apr. 30-May 2, 1963. Eng. Ext. Ser. No. 115. Eng. Bull., Purdue Univ. 48 (3):498-514. May 1964.

99. Symons, J.M., and R.E. McKinney. The biochemistry of nitrogen in the synthesis of activated sludge. Sewage and Ind. Wastes. 30:874-90. July 1958.

100. Symons, J.M., R.E. McKinney, R.M. Smith, and E.J. Donovan, Jr., Degradation of nitrogen containing organic compounds by activated sludge. Intern. J. Air Water Pollution. 4:115-38. June 1961. Also in: Advances in biological waste treatment. Eckenfelder and McCabe, Eds. Pergamon Press, London, U.K. 1963. pp 41-59.

I. Phosphorus

101. Missingham, G.A., "Occurrence of Phosphates in Surface Waters and Some Related Problems", Journal American Water Works Association, Vol. 57, No. 2 pp. 183-211.

102. Weaver, P.J., "Phosphates in Surface Waters and Detergents", Journal Water Pollution Control Federation, September 1969, Vol. 41, pp. 1647-1653.

103. Weiss, Charles M. "Relation of Phosphates to Eutrophication", Journal American Water Works Association, Vol. 61, No. 8, August 1969, pp. 387-391.

104. ________, "The Great Phosphorus Controversy", Environmental Science and Technology, Vol. 4, No. 9, September 1970, pp. 725-726.

J. Iron

105. Morgan, J.J., and W. Stumm. The role of multivalent metal oxides in limnological transformations, as exemplified by iron and manganese. In: Advances in water pollution research, Proc. 2nd Inter. Conf., Vol. 1. Pergamon Press, London, U.K., 1965. pp. 103-18.

106. Stumm, W., and G.F. Lee, The chemistry of aqueous iron. Schweiz, Z. Hydrol. 22(1):295-319. 1960.

107. Sylvester, R.O., and D.A. Carlson. A study of water quality in relation to the future. Howard A. Hanson Impoundment on the Green River, Washington. Report prepared for the Corps of Engineers, U.S. Army, Seattle District. U of Wash., Seattle, Wash. Dec. 1961. 44 pp.

K. Manganese

108. Flentje, M.E. How is your manganese? Water Works Eng. 113:288-89. Apr. 1960.

109. Ingols, R.S., and R.D. Wilroy. Mechanism of manganese solution in lake waters. JAWWA. 55:282-90. Mar. 1963.

110. Myers, H.C. Manganese deposits in western reservoirs and distribution systems. JAWWA. 53:579-88. May 1961

111. Wilroy, R.D. and R.S. Ingols. Aging of water in reservoirs of the Piedmont Plateau. JAWWA. 56:886-90 July 1964. Also published as: Yearly variation in water quality in several lakes in the southeastern United States. Proc. 2n Ann. Sanit. Conf., Nashville, Tenn. May 30-31, 1963. P.A. Krenkel, Ed., Dept. Civil Eng., Vanderbilt U. Nashville, Tenn. pp. 24-28.

L. Oxidation and persistence of organics

112. Derby, R.L. Chlorination of deep reservoirs for taste and odor control. JAWWA. 48:775-80. July 1956.

113. Douglas, N.H., and W.H. Irwin. Evaluation and relative resistance of sixteen species of fish as test animals in toxicity bioassays of petroleum refinery effluents. In: Proc. 17th Ind. Waste Conf., Layfayette, Ind., May 1-3, 1962. Eng. Ext. Ser. No. 112. Eng. Bull., Purdue U. 47 (2):57-65. Mar. 1963.

114. Hull, C.H. J. Bibliography on biochemical oxygen demand. Report No. V of the low-flow augmentation for stream-pollution control project. Div. Water Supply and Pollution Control, Res. and Trng. Br., USPHS, Grant No. WP-00153. (Project title: Low flow augmentation for stream-pollution abatement.) Johns Hopkins U., Baltimore, Md., Feb. 1961. 27 pp.

115. Jaag, O. Mechanism of self-purifications in flowing waters. Intern. Ver. Theoret. Angew. Limnol., Verhand. 14:41-58. 1959. Water Pollution Abstr. 35:Abstr. No. 1650. Aug. 1962.

116. Liebmann, H. Investigations on the influence of retention by dams on natural self-purification. In: Wasser u. Abwasser. R. Liepolt, Ed. Verlag Winkler and Co., Vienna, Austria, 1961. pp. 35-51. Water Pollution Abstr. No. 1225. Aug. 1963.

117. Mohler, J. Assessment of the self-purifying power of surface waters. Chimia. 6:229-36. 1952. Water Pollution Abstr. 28:Abstr. 471. Feb. 1955.

118. O'Connor, D.J. Organic pollution of New York Harbor-theoretical considerations. JWPCF. 34:905-19. Sept. 1962.

119. Ridenour, G.M. Studies on the effect of a small impounding reservoir on stream purification. Sewage Works J. 5:319-32. Mar. 1933.

120. Robeck, G.G., A.R. Bryant, and R.L. Woodward. Influence of ABS on coliform movement through water-saturated sandy soils. JAWWA. 54:75-82. Jan 1962.

121. Robeck, G.G., J.M. Cohen, W.T. Sayers, and R.L. Woodward. Degradation of ABS and other organics in unsaturated soils JWPCF. 35:1225-36. Oct. 1963.

122. Wayman, C.H., J.B. Robertson, and C.W. Hall. Biodegradation of surfactants under aerobic and anaerobic conditions. In: Proc. 18th Ind. Waste Conf., Lafayette, Ind. Apr. 30-May 2, 1963. Eng. Ext. Ser. No. 115. Eng. Bull. Purdue U. 48(3):578-88. May 1964.

123. Zobell, C.E., and J. Stadler. The effect of oxygen tension on the oxygen uptake of lake bacteria, J. Bacteriol. 39:307-22. Mar. 1940.

M. Methane

124. Oswald, W.J., C.G. Golueke, R.C. Cooper, H.K. Gee, and J.C. Bronson. Water reclamation, algal production and methane fermentation in waste ponds. Intern. J. Air Water Pollution. 7:627-48. Aug. 1963. Also in: Advances in water pollution research, Proc. 1st Intern. Conf. Vol. 2. Pergamon Press, London, U.K., 1964. pp. 119-40.

N. Color

125. Shapiro, J. Effect of yellow organic acids on iron and other metals in water. JAWWA. 56.1062-82. Aug. 1964.

126. Shapiro, J. Inorganic-organic interactions in natural waters. Unpublished project proposal. n.d.

O. Thermal stratification

127. Kittrell, F.W. Thermal stratification in reservoir. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanit. Eng. Center, Cincinnati, Ohio, Apr. 3-5, 1963. PHS Publ. No. 999-WP-30. June, 1965. pp. 57-67.

128. Marlier, G., The biology of tropical lakes. Folia sci. Afr. centr. 1:3-5. 1955. Water Pollution Abstr. 35: Abstr. No. 273. Feb. 1962.

P. Density flows

129. Duncan, W., D.R. F. Harleman, and R.A. Elder. Internal density currents created by withdrawal from a stratified reservoir. Report for TVA and U.S. Corps of Engineers, Norris, Tenn. Feb. 1962. 19 pp.

130. Lake Mead comprehensive survey of 1948-49. Vol. 3. A cooperative project of U.S. Dept. Interior and U.S. Dept. Navy. Feb. 1954. 366 pp.

131. Task Committee on Preparation of Sedimentation Manual. L. Density currents. J. Hydraulics Div., Proc. ASCE 89 (H5):77-87. Sept. 1963.

132. Thomas, H.E. First fourteen years of Lake Mead. U.S. Geol. Survey, Circ. No. 346. U.S. Govt Printing Off. Wash. D.C. 1954. 27 pp.

133. Wiebe, A. H. Density currents in Norris Reservoir Ecology. July 1939.

Q. Artificial destratification of impoundments

134. Bryan, J.G. Improvement in the quality of reservoir discharges through reservoir mixing and aeration. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanit. Eng. Center. Cincinnati, Ohio, Apr. 3-5, 1963. PHS Publ. No. 999-WP-30. June 1965. pp. 317-34.

135. Hooper, F.F., R.C. Ball, and H.A. Tanner, An experiment in the artificial circulation of a small Michigan Lake. Trans. Am. Fisheries Soc. 82:222-41. July 1952.

136. Lathbury, A., R.A. Bryson. and B. Lettau. Some observations of currents in the hypolimnion of Lake Mendota. Limnol. and Oceanog. 5:409-13. Oct. 1960.

137. Likens, G.E., and A.D. Hasler. Movement of radiosodium in a chemically stratified lake. Science. 131:1676-77. June 3, 1960.

138. Mercier, P., and S. Gay. Effects de l'aeration artificielle souslacustre au Lac de Bret. Rev. Susse D'Hydrologie. 16(2): . 1954.

139. Patriarche, M. H. Air-induced winter circulation of two shallow Michigan lakes. J. Wildlife Management. 25:282-89. July 1961. Water Pollution Abstr. 35:Abstr. No. 894. May 1962.

R. Evaporation control

140. LaMer, V.K., Ed. Retardation of evaporation by mono-layers. Academic Press, New York, N.Y., 1962. 277 pp.

141. Meyers, J.S. Evaporation from the 17 western states. U.S. Geol. Survey. Profess. Papers No. 272-D. U.S. Govt. Printing Office, Washington, D.C. 1962.

142. Task Group Report. Survey of methods for evaporation control. JAWWA. 55:157-68. Feb. 1963.

S. Thermal pollution

143. Arnold, G.E. Thermal pollution of surface supplies. JAWWA. 54:1332-46. Nov. 1962.

144. Cairns, John, Jr., "Thermal Pollution - A Cause for Concern", Journal Water Pollution Control Federation, January 1971, Vol. 43, No. 1, pp. 55-66.

145. Churchill, M.A. Control of temperature through streamflow regulation. In: Symposium on streamflow regulation for quality control. Robert A. Taft Sanit. Eng. Center, Cincinnati, Ohio, Apr. 3-5, 1963. PHS Publ. No. 999-WP-30. June 1965. pp. 179-92.

146. Duttweiler, D.W., A mathematical model of stream temperature. Unpublished doctoral thesis, Johns Hopkins U., Baltimore, Md. 1963. 139 pp.

147. Eckel. O. Temperature conditions in impounded waters. In: Wasser u. Abwasser. R. Liepolt, Ed. Verlag Winkler and Co., Vienna, Austria, 1961. pp. 170-89. Water Pollution Abstr. 36: Abstr. No. 1231. Aug. 1963.

148. Eldridge, E.F., Ed. Water temperature influences, effects, and control. In: Proc. 12th Pacific Northwest Symposium on Water Pollution Research. USDEW, PHS Pacific Northwest Water Lab., Corvallis, Ore. Nov. 7, 1963. 159 pp.

149. Hoak, R.D. The thermal pollution problem. JWPCF. 33:1267-76. Dec. 1961.

III. Influence of impoundment releases on downstream water quality

A. Influence on quality

150. Fish, F.F. Effect of impoundment on downstream water quality. Roanoke River, N.C. JAWWA. 51:47-50. Jan. 1959.

151. Hall, B.M., Jr. Reregulation of impounded water quality. Chattahooche River, Ga. JAWWA. 51:33-42. Jan. 1959.

152. Pfitzer, D.W. Investigations of waters below storage reservoirs in Tennessee. Presented at 5th Ann. Conf. Southeast Assoc. Game and Fish Commissioners. (Game and Fresh Water Commission, Tallahassee, Fla.) 1952.

B. Turbulent diffusion and natural mixing

153. Krenkel, P.A. Turbulent diffusion and river waste assimilative capacity. Progress report: May 1, 1962-May 1, 1964. Tech. Rept. No. 3. Sanit. and Water Resources Eng., Vanderbilt Univ. Nashville, Tenn. May 1964. 55 pp. Appendices.

154. Thomas, H.A., Jr., and R.S. Archibald. Longitudinal mixing measured by radioactive tracers. Trans. ASCE 117:839-50. 1952.

155. Wisniewski, T.F. Cross-section surveys as a method of evaluating the self-purification capacity of a stream. TAPPI. 42:67-70. Jan. 1959.

6.0 LAND USE FUNCTIONS IN WATER QUALITY MANAGEMENT

As the ratio of percent removal to cost of removal decreases sharply, it is becoming readily apparent that advanced waste treatment facilities and water quality standards are not the total answer to improving water quality. Since water quality is so dependent upon land use, it is becoming more rapidly accepted that controlled land use is an essential part of water quality management. As mentioned earlier, all forms of contaminant entry can be traced to either point or non-point sources. And all these sources can be directly related to land use.

Pollution abatement measures are successful in treating point sources of contamination which enter our waterways. However, the need to control non-point sources of pollution are necessary if desired water quality is to be achieved in many areas. Since pollution abatement programs are relatively ineffective against non-point sources of pollution, the need for preventive measures should now be the point of attack. Runoff, the chief contributor to non-point sources of pollution, can be divided into 3 categories: agricultural, urban, and resource extraction.

Pollution from agricultural lands encompasses the effects of grazing, concentrated animal growing, crop production, refuse and manure disposal, and road construction and maintenance. Animal growing can impose bacterial, BOD and nutrient loads of significant proportions on small streams during rainfall and as mentioned, snow melt runoff episodes. Fertilizers and pesticides are other contaminants present in agricultural runoff. Heavy animal traffic and poor plowing techniques often result in heavy sediment influxes to nearby streams.

Urban land runoff includes surface drainage from streets and parking lots, discharges from combined sewer systems or from separate storm sewer systems, and from unsewered areas of urban composition. The combined sewer overflow is a special case of urban land runoff in that such discharges carry large quantities of sanitary sewage. The contaminant contributions from urban land runoff are sizeable with high concentrations of BOD, COD, total solids, nutrients, heavy metals, and chlorides (from street deicing practices).

The large amounts of total solids in urban land runoff emphasizes the significance of sediment from urban construction involving housing developments, shopping centers, roads and highways.

Erosion from roads and highways is not limited to urban areas and is an important factor throughout the environment. Indeed, the secondary road system is believed to be an extremely important source of sediment in rural areas as emphasized by the Gale River and I-93 relationship mentioned.

A USGS* study of sediment movement from suburban highway construction in Fairfax County, Va., reported that with normal precipitation erosion in construction areas would be about 10 times that normally expected from cultivated land, 200 times that from grassland, and 2000 times higher than from forest land. The intensity of storm runoff was found to have an important influence on erosion, but somewhat less than the volume of runoff. The average rate of runoff varied greatly from storm to storm. Erosion was found to vary considerably between seasons, ranging between a high of 24 tons per acre during the 2nd quarter to a low of 7 tons per acre during the 3rd quarter.

The practices used in the extraction of natural resources in the past, has not been satisfactory from the standpoint of water quality. Quarrying for sand and gravel, the mining of coal, sulfur, oil and other minerals and silvicultural practices add tremendous contaminant and sediment loads to waterways. Specific pollutants vary with the type of resource extraction. However, erosion and sedimentation are possible at any site where proper site planning, construction techniques, and planting are not carried out. This is especially true in logging operations. Other major threats to water quality come from salt water which is a by-product of oil extraction along with oil spills themselves and acid mine drainage from coal mines and their spoils. Unlike most other activities, negative side effects of mining can be detected long after the mining operations have been discontinued unless proper reclamation measures are taken.

If non-point sources of pollution are to be controlled, then provisions for erosion and sediment control should be incorporated in areawide, community, and project plans. Area planning should include provisions for roads, highways and other transportation facilities, subdivision and lot development, industrial and commercial development, surface mining and other resource extraction operations, service or recreational areas, utilities, water impoundments and waterway construction, agricultural & silvicultural practices and highway construction and maintenance.

* Rice, R.B., Guy, H.P. and Ferguson, G.E., "Sediment Movement in an Area of Suburban Highway Construction, Scot Run Basin, Fairfax County, Va.", 1961-64, USGS W-S Paper 1591-E, 1969.

Communities should fit their development plans to climatic factors, topography, soils and vegetative cover, reduce the area and duration of exposed soils, retain and protect natural vegetation wherever feasible, cover disturbed soils with mulch or vegetation, mechanically retard runoff, erosion, and sediment in runoff water, and provide effective accomodation for increased runoff caused by changing soil and surface conditions during and after development*.

A new emerging concept is the importance of reserving land for functional open space. Past practices have usually left only the land that is unfit for any other use to be used for recreation and open space. Now land is being reserved for the value of the open space itself. For example, New Jersey is saving land to protect its groundwater recharge areas.

The practice of reserving a strip of land in the floodplain of a river, now being considered in many areas, is an effective method for reducing pollution from land runoff. The maintenance of this buffer strip alongside all streams applies to forest, agriculture, and urban lands alike. This well-vegetated strip would effectively reduce the influx of phosphorus, pesticides, and suspended particulate matter. It would stabilize river banks, enhance the appearance of water bodies and offer some area for outdoor recreation such as hiking, camping and hunting. This practice prevents excessive flood plain encroachment and leads to reduced flood damages.

Hence, land use controls can be used as an effective means of water quality management and it is rapidly becoming an economic necessity to use these controls to maintain contiguous land uses compatible with water use classifications.

---

* From "Community Action Guidebook for Soil Erosion and Sediment Control", published by the National Association Counties Res. Foundation under an FWQA grant (March, 1970), by Powell, M.D., Winter, W.C., and Bodwitch, W.P.

7.0 WATER QUALITY RECONNAISSANCE OF SIX SELECTED TRIBUTARIES

Introduction

The following section presents a water quality analysis of six selected tributaries in the Connecticut River Basin. The six watersheds were selected so as to be coincident with the watersheds analyzed by the Bureau of Sport Fisheries and Wildlife. They are: the Deerfield and Westfield Rivers in Massachusetts, the Ammonoosuc River in New Hampshire, the White and Passumpsic Rivers in Vermont and Whetstone Brock in Vermont. In order to prevent repetition, the more thorough descriptions of the watersheds are presented in the section prepared by the Bureau of Sport Fisheries and Wildlife. The Environmental Protection Agency will limit its coverage to a general description and a water quality reconnaissance.

The station numbers indicated on the graphs and the accompanying maps are the same stations and numbers used by the states in their water quality sampling. The numbers in many cases are not consecutive due to the elimination of the station, obsolescence of the data, or the situation of the sampling point on some secondary stream of the tributary being discussed. Any significant effects that these secondary streams may have on the tributary's water quality will be pointed out in the discussion.

The analyses are based on open water or warm weather conditions, since the data used was collected primarily during the spring, summer, and early fall months. These sampling periods, although restricted by time, are taken during the interval which often exerts the greatest stress on a waterway.

Measures of Water Pollution*

The term "water pollution" has acquired many connotations. Literally, the word pollute means "render impure"; thus, in this sense, any water containing matter other than its chemical constituent of two parts hydrogen to one part oxygen would be considered polluted. Such "pure" water; however, is never found in natural bodies; the ecological balance in a waterbody is dependent on the presence of other materials. In this report, water pollution refers to a condition which is in a contravention of the Water Quality Standards. Pollution degrades the physical, chemical, and bacterial quality of a waterbody and can make it unsightly, malodorous, and a health hazard. Under such conditions, its use is sharply limited. Pollution occurs mainly through the discharge of wastes from homes and industries. The various types of pollution are: (1) oxygen-demanding, such as originates from domestic sewage and certain industrial wastes, (2) toxic materials as in some industrial wastes, (3) radioactive, (4) thermal, (5) bacterial, (6) oil, (7) physical and aesthetic unattractiveness. Stormwater runoff from both urban and rural areas can also add pollutants to a waterbody.

---

*NOTE: Taken from the report prepared by the Water Quality Section, Division of Water Pollution Control, Massachusetts Water Resources Commission, Westfield River Study.

The extent of pollution in a particular waterbody is determined by measuring certain chemical and biological constituents and properties. Chemical constituents, such as dissolved oxygen, phosphates, and metals, are generally measured in milligrams per liter (mg/l); since the unit weight of water is 1.0 grams per milliliter, milligrams per liter are roughly equivalent to parts per million for a solution which is mostly water.

Dissolved Oxygen (D.O.) refers to the uncombined oxygen in water which is available to aquatic life. Since this oxygen is consumed more rapidly in the decomposition of wastes, the D.O. gives an instantaneous picture of the condition of a waterbody. Time of day and temperature of the water are important in interpreting D.O. levels. Temperature affects the amount of oxygen which water can contain. Time of day is related to the effects of algae. Algae consume oxygen through respiration throughout the day and night. During daylight hours, they add oxygen through photosynthesis. D.O. levels are therefore generally highest during the afternoon and lowest before sunrise.

Biochemical Oxygen Demand (BOD) measures the amount of oxygen required by bacteria to decompose organic matter. The BOD is gradually exerted, consisting of two stages. In the first stage, carbonaceous matter is stabilized while nitrogenous substances are broken down in the second stage. The second stage (nitrification) usually begins after seven days. The ultimate, or total, BOD from both stages may require an incubation period of 30 days or more. Through recurrent use, the 5 day BOD has become the standard test used in water quality analysis.

Chemical Oxygen Demand (COD) refers to the amount of oxygen required to chemically oxidize waste material. Since some of the organic matter in a waste can not be decomposed by microorganisms but can be broken down by chemical oxidation, the COD is generally greater than the BOD. The COD is especially useful in analyzing a waste that contains a great deal of non-biodegradable matter.

Total Solids measures all solids in water including suspended and dissolved, organic and inorganic. They are measured by evaporating the water from a sample of known volume and weighing the residue remaining. The residue then can be ignited in a laboratory furnace to determine the organic portion. The loss on ignition is considered organic and the remaining residue, known as fixed solids, is considered to be inorganic.

Suspended Solids are those which can be removed by passing the water through a filter. The remaining solids are called dissolved solids. Suspended solids provide a good measure of the efficiency of a sewage treatment plant; primary treatment should remove about 50 percent of the suspended solids while secondary treatment should remove about 90 percent.

Coliform Bacteria are found in abundance in the intestinal tract of warm-blooded animals. They are not harmful in themselves, but their presence indicates that pathogenic bacteria also may be present. Since they can be detected by relatively simple test procedures, coliforms are used to indicate the extent of bacterial pollution from sewage. Bacterial tests usually measure the fecal coliforms and the total coliforms. Fecal coliforms make up about 90 percent of the coliforms discharged in fecal matter. Non-fecal coliforms may originate in soil, grain, or decaying vegetation. The rate of destruction or removal of coliforms from water and sewage is substantially parallel to that of pathogenic bacteria.

pH measures the hydrogen ion concentration on an inverse logarithmic scale ranging from 0 to 14. pH values under 7 indicate more hydrogen ions and therefore more acidic solution; pH values over 7 indicate less hydrogen ions and therefore more alkaline solutions. A pH of 7 indicates a neutral solution. Alkalinity is a quantitative measure of the alkaline materials present while acidity is a quantitative measure of acidic materials.

Nutrients are compounds which act as fertilizers for aquatic organisms. Small amounts are necessary to the ecological balance of a waterbody, but excessive amounts can upset the balance by causing excessive growths of algae and other aquatic plants. Sewage discharged to a waterbody usually contains large amounts of carbon, nitrogen, and phosphorus; all considered to be nutrients. The concentration of carbonaceous matter is reflected in the BOD test. Additional tests are run to determine the concentration of nitrogen and phosphorus.

Phosphorus appears in waterbodies in combined forms known as ortho- and poly-phosphates and organic phosphorus. The majority of the phosphorus contained in domestic sewage and industrial wastes comes from detergents. Additional phosphorus may enter a waterbody in agricultural runoff where fertilizers are used.

Nitrogen in the form of organic nitrogen decomposes into ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Since each decomposition reaction is dependent on the preceding one, the progress of decomposition can be determined in terms of the relative amounts of these four forms of nitrogen.

Ammonia Nitrogen is present in sewage and is also generated from the decomposition of organic nitrogen. It can also be formed when nitrites and nitrates are reduced. Ammonia is particularly important since it has high oxygen and chemical demands and is also toxic to fish.

Nitrite Nitrogen is the oxidation product of ammonia. It has a fairly low oxygen demand and is rapidly converted to nitrate. The presence of nitrite nitrogen usually indicates that active decomposition is taking place.

Nitrate Nitrogen is important since it is the end product in the aerobic decomposition of nitrogenous matter. Nitrogen in this form is readily available to plants.

Turbidity is the measure of the clarity of a water sample. It is expressed in Jackson Standard Units which are related to the scattering and absorption of light by the water sample.

Color is determined by visual comparison of a sample with known concentrations of colored solutions and is expressed in standard units of color. Certain waste discharges may turn water to colors which cannot be defined by this method; in such cases, the color is expressed qualitatively rather than numerically.

Specific Conductance yields a measure of a water sample's capacity to convey an electric current. It is dependent on temperature and the concentration of ionized substances in the water. Distilled water exhibits specific conductance of 0.5 to 2.0 micromhos per centimeter while natural waters show values from 50 to 500 micromhos per centimeter.

Alkalinity in a water is a measure of its capacity to neutralize acids. The alkalinity of natural waters is due primarily to the salts of weak acids, although weak or strong bases may also contribute. Bicarbonates represent the major form of alkalinity, since they are formed in considerable amounts from the action of carbon dioxide upon basic materials in the soil.

Under certain conditions, natural waters may contain appreciable amounts of carbonate and hydroxide alkalinity. This condition is particularly true in surface waters where algae are flourishing. The algae remove carbon dioxide, free and combined, from the water to such an extent that pH values of 9 to 10 are often obtained. The alkalinity in natural waters is caused by three major classes of materials; hydroxides, carbonates, and bicarbonates. The alkalinity of a water has little sanitary significance but highly alkaline waters are usually unpalatable. Sudden increases in alkalinity often indicate algae blooms, a change in geology or introduction of chemically treated waters. High concentrations of alkalinity, hardness and sulfates cause additional water quality problems which often require specific treatment before the water can be economically used.

Temperature changes often induce secondary effects in a waterbody. Higher temperatures mean lower dissolved oxygen concentrations. Temperature changes induce ecological disruptions if the change is significant. The subject of thermal pollution is presently a controversial issue between ecologists and industrialists.

The above parameters are measured in most water quality surveys. Other constitutents such as metals or radioactivity are measured in areas when particular problems are known to exist. Microscopic examinations are conducted on most surveys to measure the amount of algae and other microorganisms present. Additional samples of the river bottom are usually collected in order to determine the types of deposits present. Decomposition of organic suspended matter which settles to the bottom will exert an oxygen demand on the water.

Two types of samples are collected for analysis: grab and composite. A grab sample is an instantaneous sample collected to show conditions at a particular time. Composite samples are collected over a period of time at specific intervals, giving a better picture of the overall water quality situation for the time covered.

Due to the limited amount of available analagous data, the tributaries are discussed primarily in terms of six parameters; BOD, DO temperature, coliforms, solids, and alkalinity. When other parameters become important and some data is available on the river in question, the parameter will be discussed in the narrative portion of the reconnaissance.

7.1 The Westfield River Basin

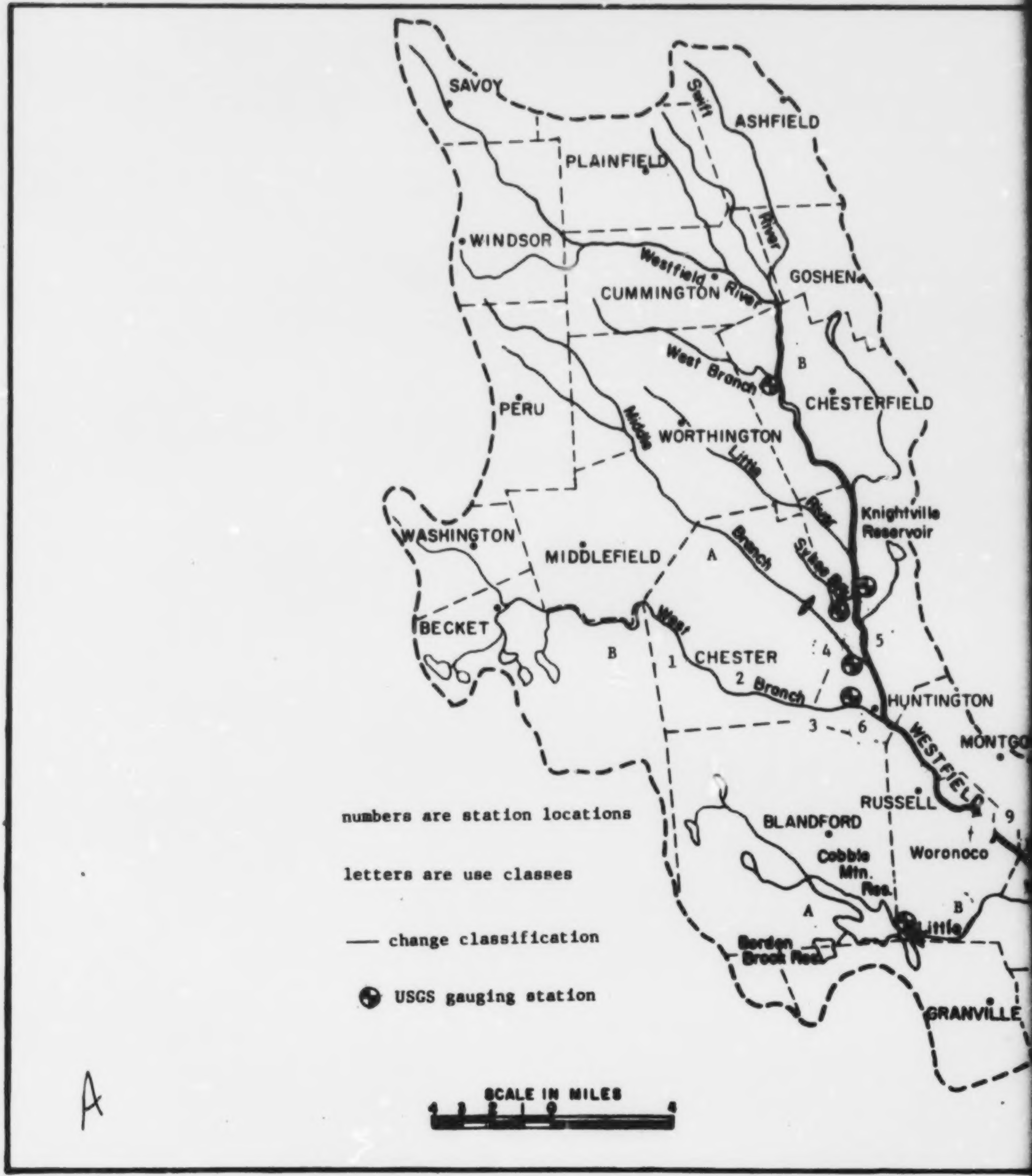
From the Berkshire Hills to the Connecticut River, the Westfield River Basin covers an area of 517 square miles. Much of this area is mountainous, and therefore sparsely populated. Most of the basin's population is concentrated in the southeastern corner in the municipalities of Agawam, Holyoke, Westfield, and West Springfield. Total population of the basin is about 100,000.

The Westfield River begins in Savoy at a point over 2,000 feet above sea level. Flowing southeast, the river falls 1,000 feet in the first 14 miles. It is joined in Huntington by the Middle and West Branches. The slope of the river gradually decreases below this point as it nears the flood plain of the Connecticut River. In Westfield, the river is joined by the Little River. Since there is another tributary stream in Huntington with the same name; this one is referred to as the Westfield Little River.

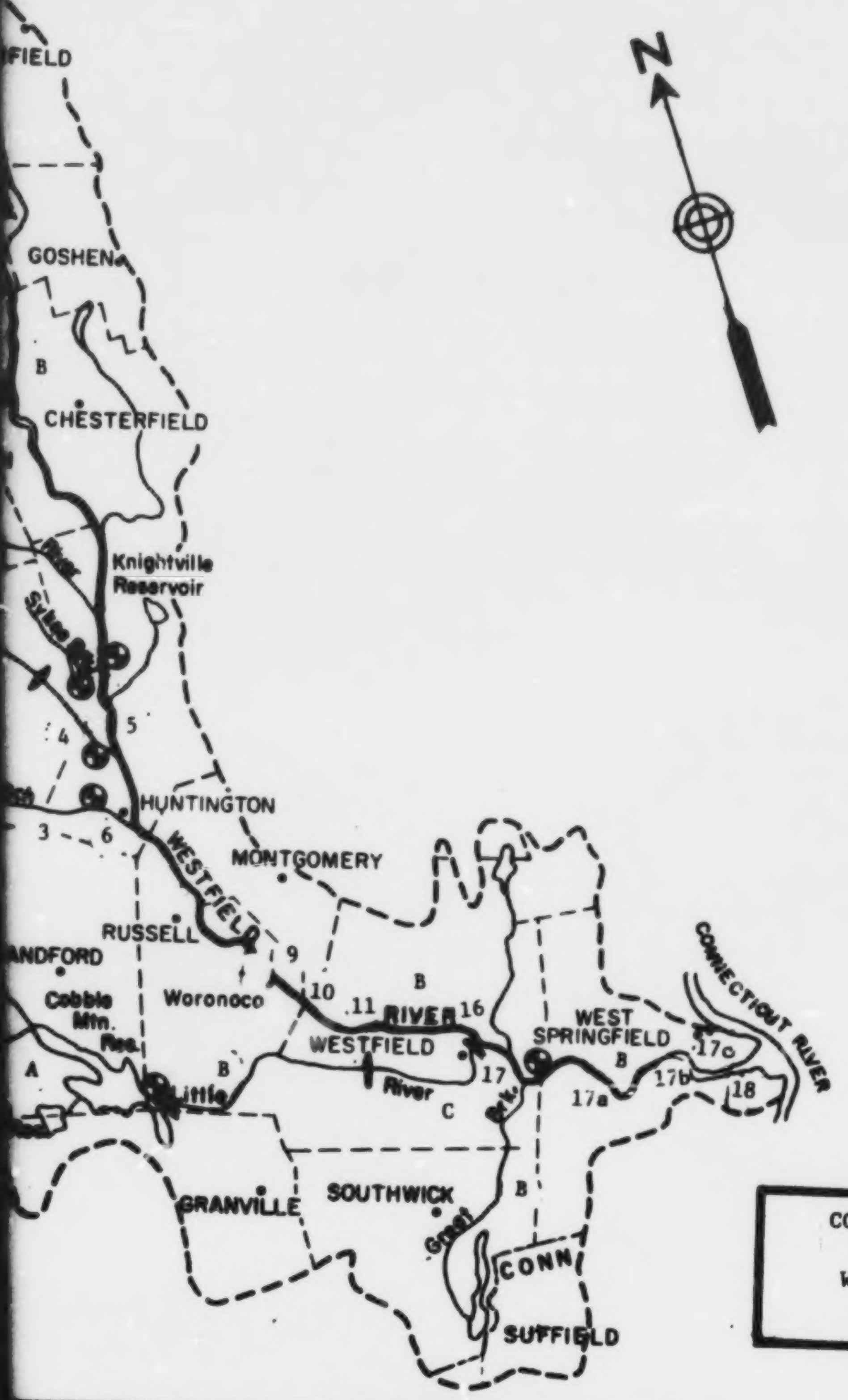
After leaving Westfield, the river forms the town line between West Springfield and Agawam for ten miles before joining the Connecticut River. Three dams are located in this reach. A USGS gage is located 8.4 miles above the mouth of Westfield. Average flow here is 929 cubic feet per second while the seven day, 1-in-10 year low flow is 99 cfs.

The Middle Branch of the Westfield River begins in the Town of Peru and flows 18 miles to join the Main Branch 27.7 miles above its mouth. This stream falls 1,250 feet in its course. Average flow at the Huntington USGS gage (0.4 miles above the mouth of the Middle Branch) is 102 cfs. Average flow in the Main Branch at the gage located two miles above the confluence is 317 cfs.

In Becket, the West Branch of the Westfield River is formed by the confluence of Depot and Yokum Brooks. This branch flows 17.5 miles through Becket, Middlefield, and Chester, falling 840 feet before joining the Main Branch in Huntington, 25.5 miles above its mouth. At the USGS gage in Huntington, 1.5 miles above the confluence with the Main Branch, the average flow is 181 cfs. This branch is parallelled closely for much of its length by U.S. Route 20, which also follows the Main Branch from the confluence of the two to West Springfield. Most of the older roads in this part of the state were built along rivers as these were the easiest routes between the mountains.


SAVOY
ASHFIELD
Swift
PLAINFIELD
River
WINDSOR
Westfield
River
GOSHEN
CUMMINGTON
West Branch
B
CHESTERFIELD
PERU
Middle
WORTHINGTON
Little
River
Knightville
Reservoir
WASHINGTON
MIDDLEFIELD
A
Branch
Sykes Bk.
BECKET
West
B
1
CHESTER
4
5
2
Branch
HUNTINGTON
3
6
WESTFIELD
MONTGO
RUSSELL
9
BLANDFORD
Woronoco
Cobble
Mtn.
Res.
A
B
Little
Borden
Brook Res.
GRANVILLE
numbers are station locations
letters are use classes
— change classification
USGS gauging station
SCALE IN MILES
4 3 2 1 0 4

A


N
FIELD
GOSHEN
B
CHESTERFIELD
River
Knightville Reservoir
Sykes Bk.
4
5
HUNTINGTON
3
6
WESTFIELD
MONTGOMERY
RUSSELL
ANDFORD
9
Cobble Mtn. Res.
Woronoco
10
11
RIVER
16
B
WEST SPRINGFIELD
CONNECTICUT RIVER
17c
WESTFIELD
17
B
17b
18
A
B
Little
River
C
Bk.
17a
B
GRANVILLE
SOUTHWICK
Great
CONN
SUFFIELD

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY
Westfield River Basin
Map 7.1

B

The Westfield Little River begins at the outlet to Cobble Mountain Reservoir in Blandford. This reservoir provides water for the City of Springfield. From the outlet, the river flows 13 miles through Russell and Westfield to join the Westfield River.

Major industries in the basin include the manufacture of paper and abrasives. The three villages in the Town of Russell are each built around a paper mill. Other mills are located in Westfield and West Springfield. Abrasives manufacture takes place in Chester, along the West Branch, and in Westfield. These are "wet" industries and result in waste discharges to the rivers.

Recreation is becoming increasingly important to the economy of the region. As the nearby Springfield Metropolitan Area grows, more and more people look to the Westfield Valley for camping, fishing, boating, and swimming. Water Resources are, therefore, vitally important to the area.

The water quality data used for this reconnaissance was collected in the Summer of 1965 by the Massachusetts Department of Public Health, as part of a major study of the Connecticut River Basin. All of the data obtained from surveys on the Westfield River will be used in the development of a mathematical model for the Westfield River, which will provide the basis for the Final Basin Plan for the control of water pollution in the Westfield River Basin.

Map 7.1 shows the sampling stations used for this survey. It also indicates the water quality classifications established for the Westfield River Basin. With one exception, the entire river basin is classified either A or B, the exception being a C classification on the lower portion of the Little River.

Graphs 7.1 (a-f) indicate the changes in selected water quality parameters as one travels up the Main, Middle and West Branches of the Westfield River. Dissolved oxygen appears to be above the limits of 5 mg/l established for the A and B classifications except immediately below the confluence of the Little River. The lower dissolved oxygen indicates the influence of the pollution load carried by the Little River. Temperature varies 8°C during the River survey, but this can be explained primarily by the fact that some stations were sampled only during June and this would account for the lower temperatures recorded. Alkalinity within the basin appeared to be fairly constant. There was some increase after Station 11 which accounts for the increased industrial discharges in the greater West Springfield area and the influence of the Little River which enters the Westfield between Stations 16

Preceding page blank

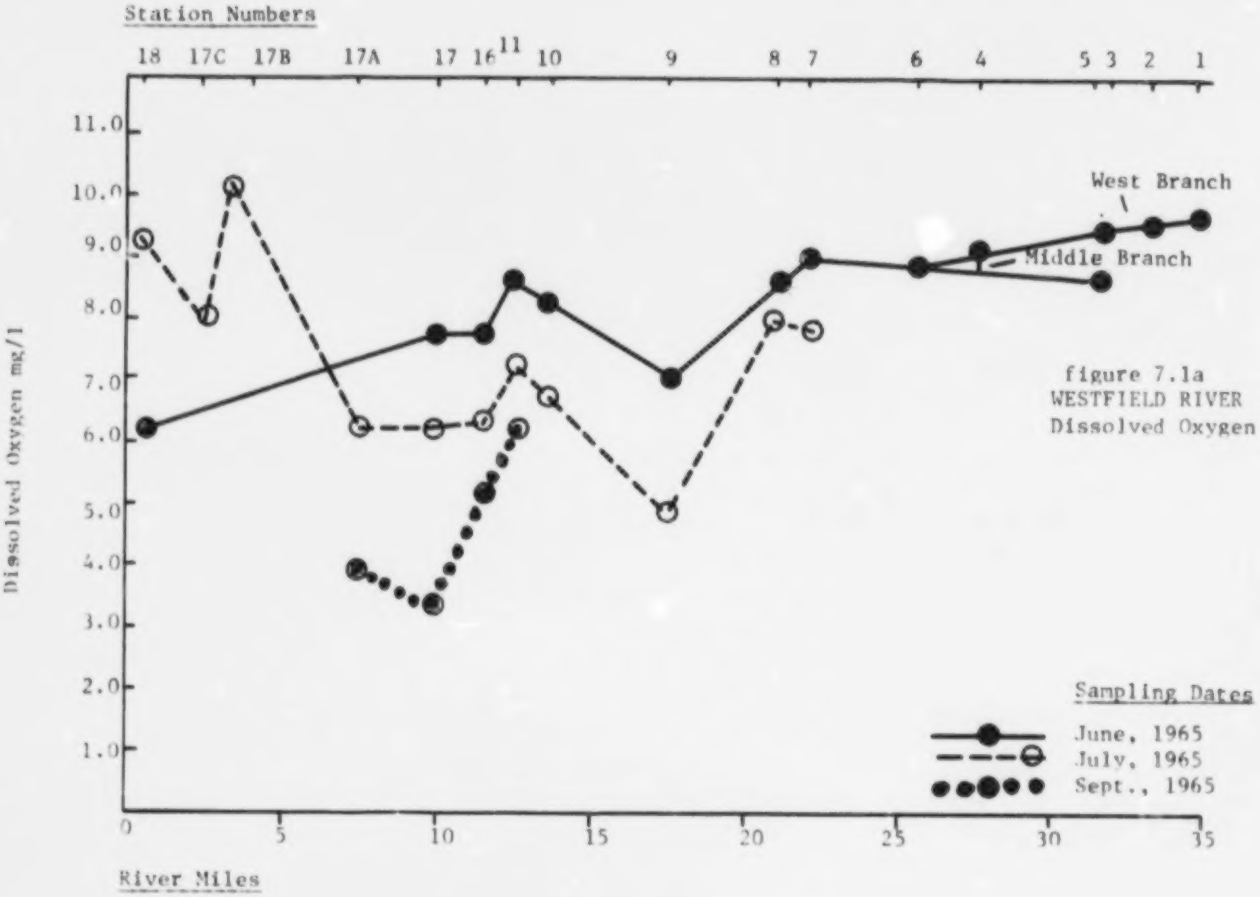


figure 7.1a
WESTFIELD RIVER
Dissolved Oxygen

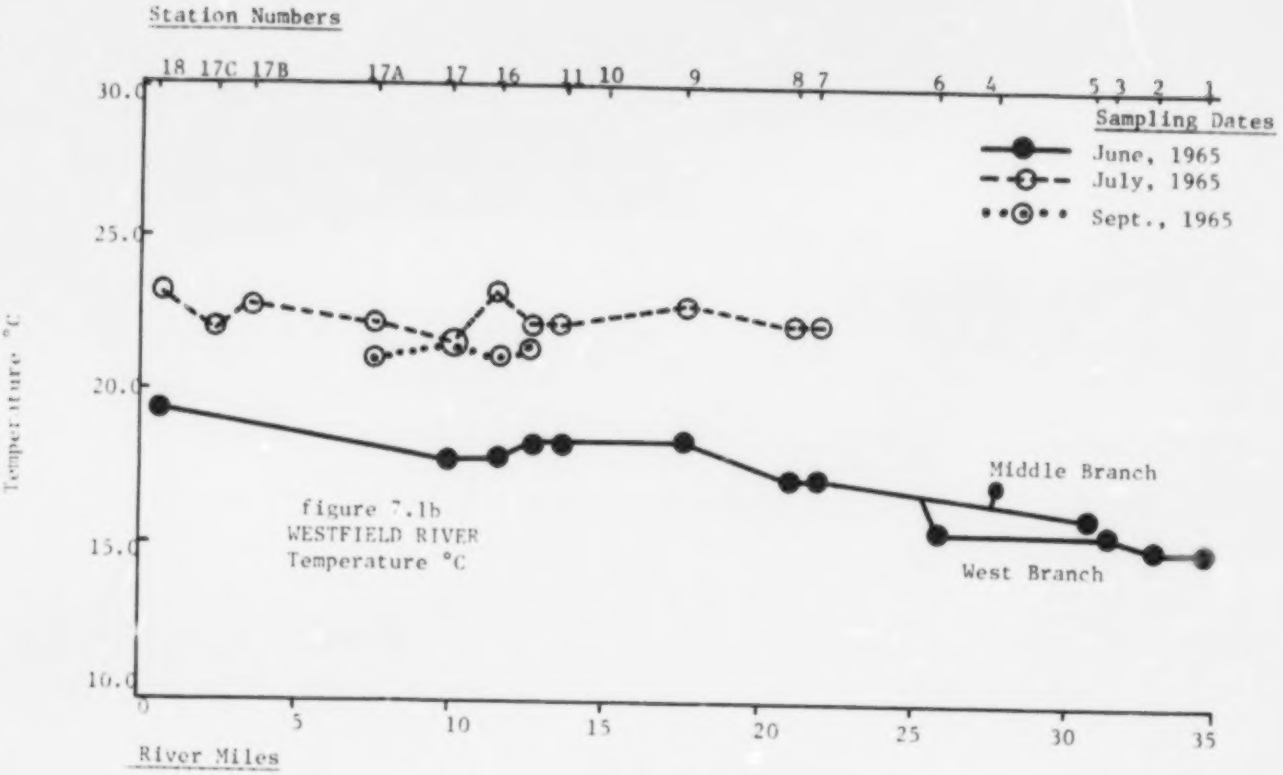


figure 7.1b
WESTFIELD RIVER
Temperature °C

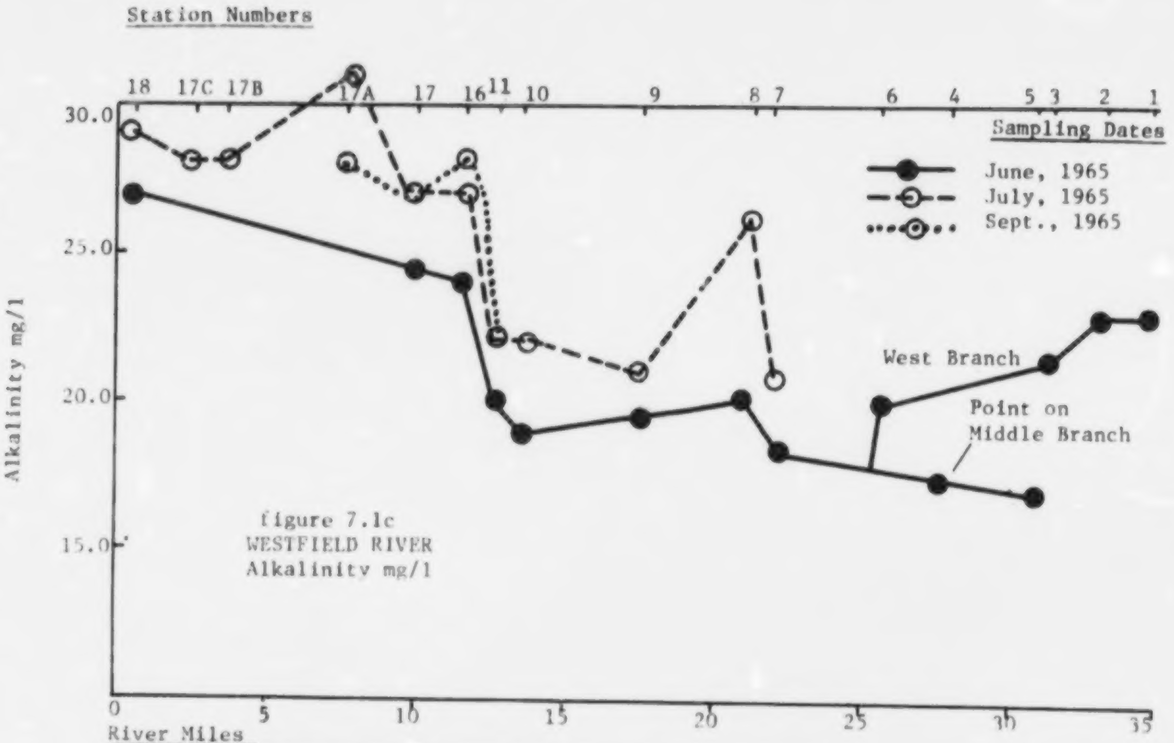


figure 7.1c
WESTFIELD RIVER
Alkalinity mg/1

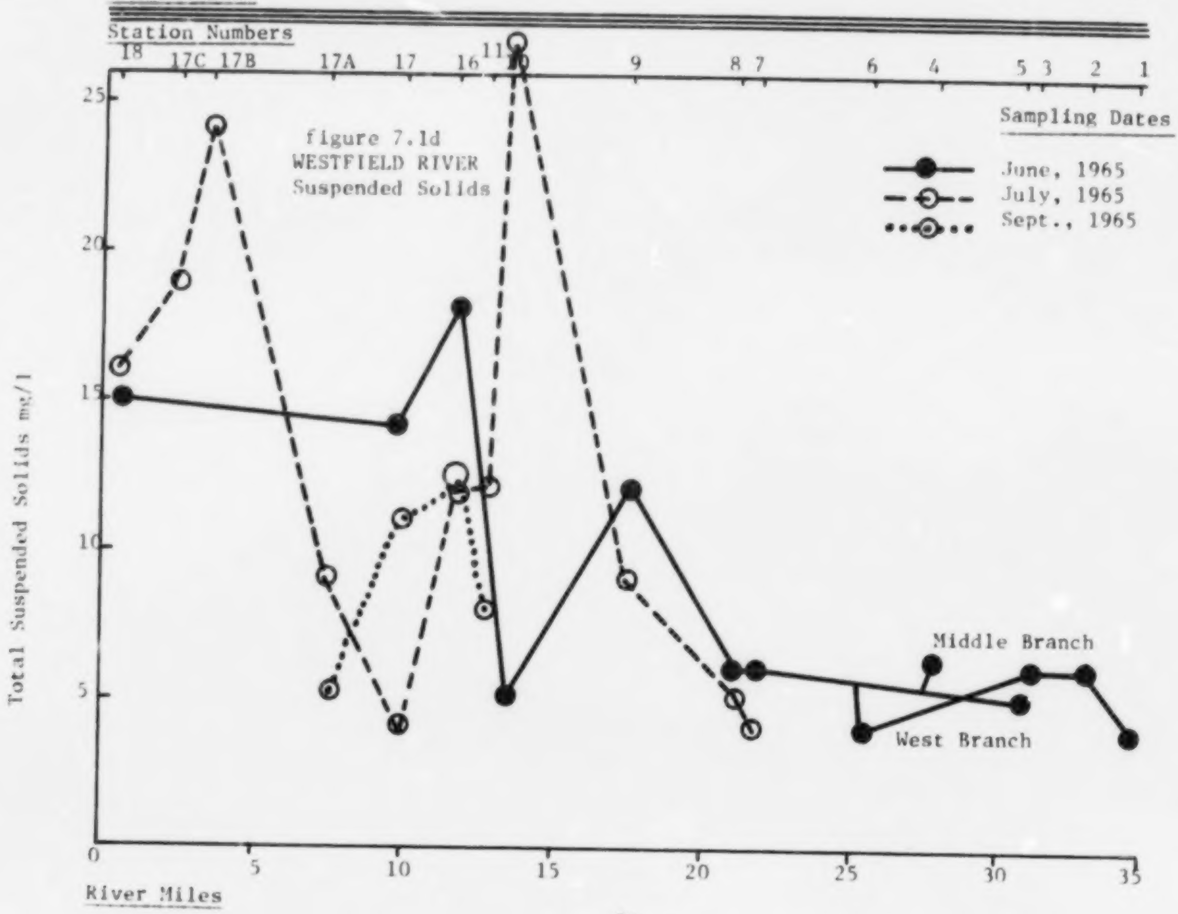


figure 7.1d
WESTFIELD RIVER
Suspended Solids

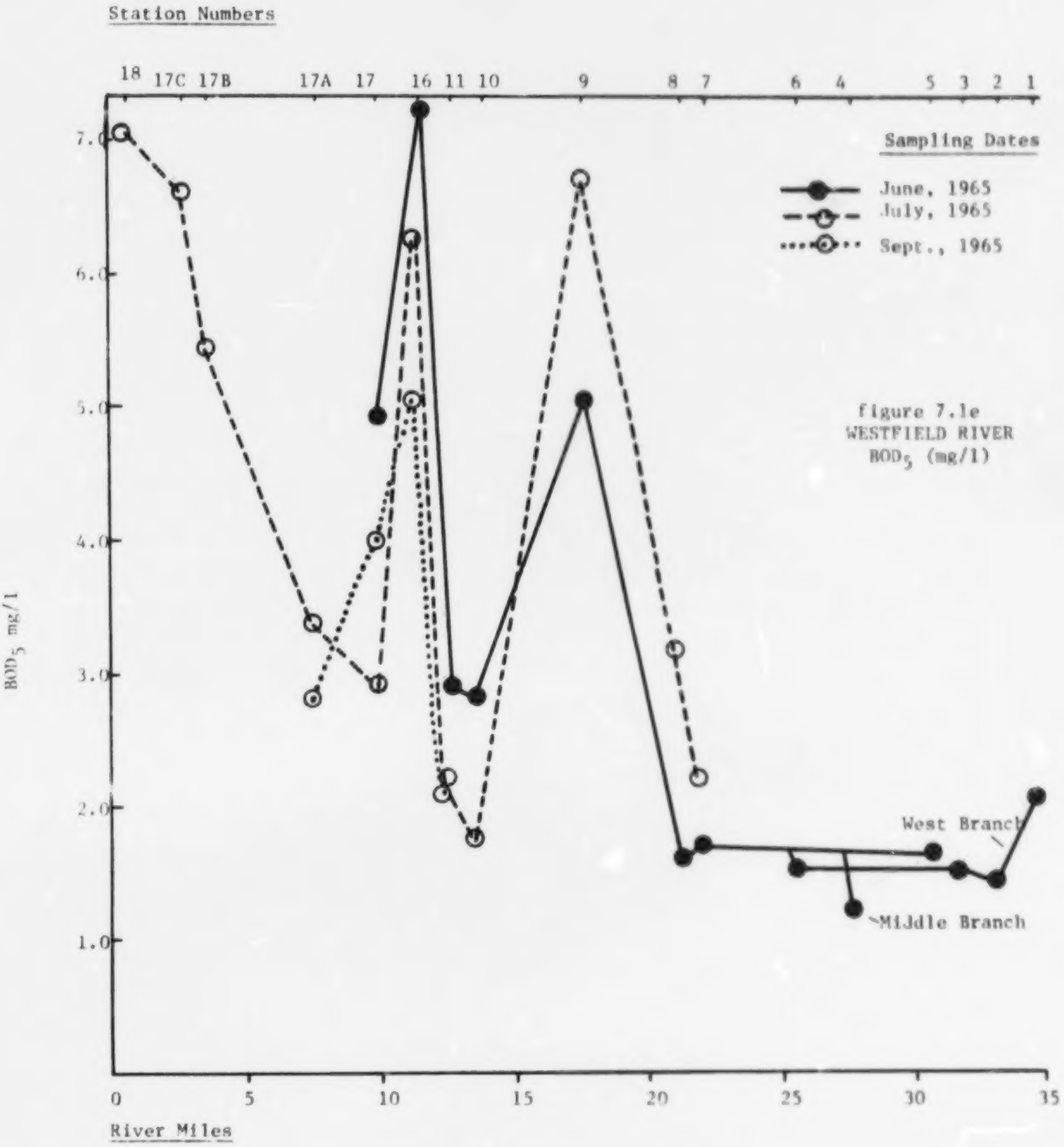


figure 7.1e
WESTFIELD RIVER
BOD$_5$ (mg/l)

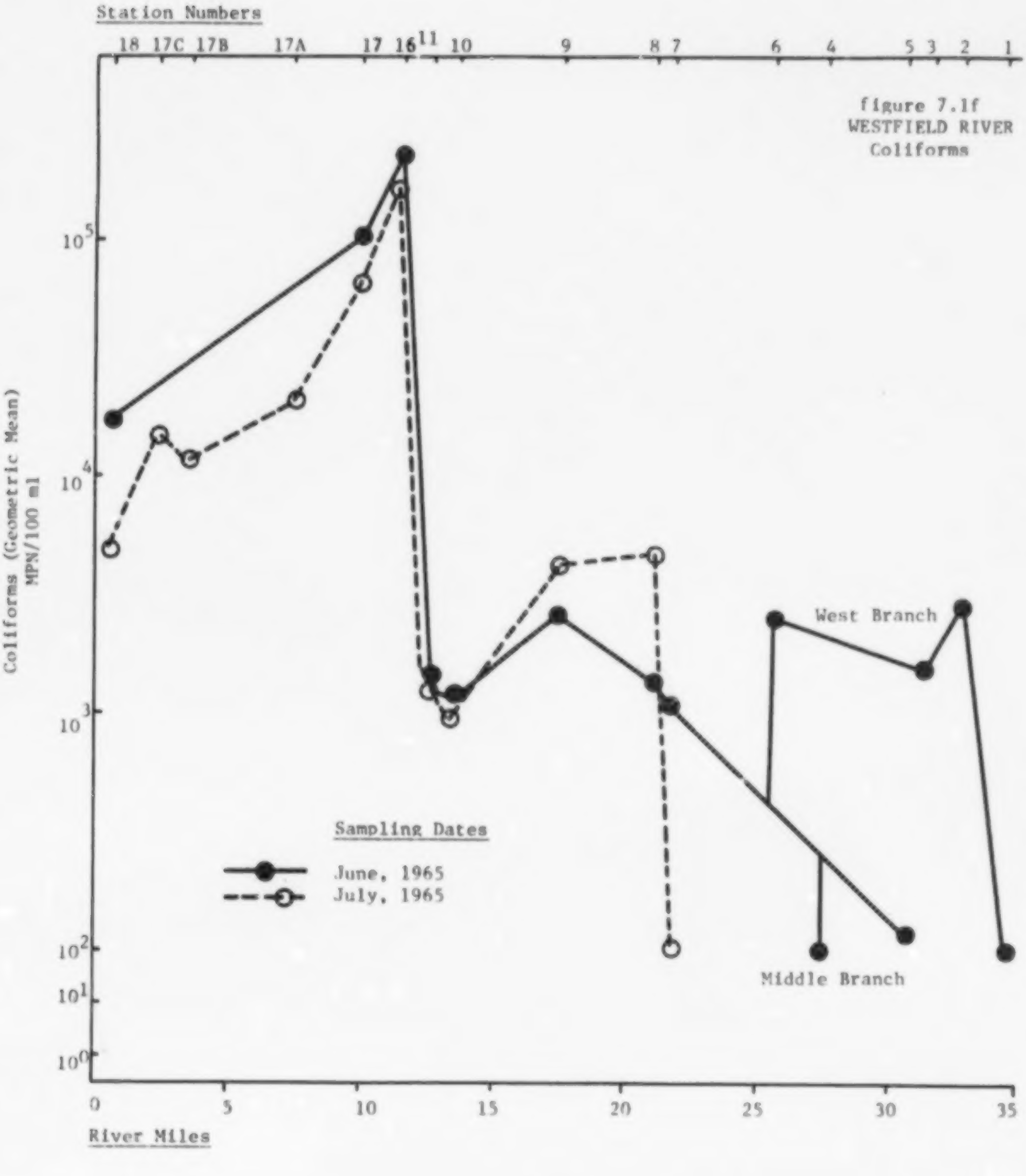


figure 7.1f
WESTFIELD RIVER
Coliforms

and 17. Alkalinity measurements in the lower Little River were 10-15 mg/l greater than those measured in the upper Main Branch of the Westfield above Station 11. The suspended solids concentration shows a significant peak at Station 17B. The concentration although not very high, does indicate the influence of urbanization and industrialization in this reach of the river.

The three peaks indicated in the BOD graph might indicate the presence of particular nearby discharges. The peak at Station 17C indicates the effects of the urbanized area of West Springfield. The peak at Station 16 could indicate the effects of the Westfield, Massachusetts' sewage treatment plant and the series of stormwater outfalls present in the town. The peak at Station 9 could indicate the effects of the Strathmore Paper Company, the Woronoco treatment plant, and other industries recorded by BSFW* and in Appendix D of the Comprehensive Report. In all instances, the parameters not only show the effects of local discharges, but also carry residual loads from further upstream discharges.

In all sampling stations on the Westfield River, except at Station 1, 4, 5 and 7, class B standards are violated in respect to coliform counts. Stations 16 though 18 had tremendous coliform counts indicating the effects of the urban development in Westfield, Agawam and West Springfield. These coliform concentrations reflect influxes of domestic effluent and urban runoff. By 1977, the adopted classification standards will have to be met through the installation of advanced waste treatment.

On the whole, the Westfield River appears to have a relatively good water quality. Hopefully, with advanced treatment practices, the class C portion of the Little River will be upgraded.

7.2 The Deerfield River Basin

The Deerfield River begins in southwestern Vermont and flows in a generally southward direction, entering Massachusetts at the Rowe-Monroe town line. It flows southwest to the Town of Florida, then turns east through Savoy, Charlemont, and Buckland to Shelburne. There it turns southeast, flowing through Conway to Deerfield where it turns northeast, joining the Connecticut River at the Deerfield-Greenfield town line. Major tributaries include the Green and North Rivers which begin in Vermont and join the Deerfield in Greenfield and Shelburne, respectively.

---

*Bureau of Sport Fisheries and Wildlife; now U.S. Fish and Wildlife Service

The Deerfield drains an area of 664 square miles (424,960 acres) of which about 380 are in Massachusetts. The Massachusetts portion contains an estimated population of 32,500. The total length of the river is 73 miles of which 46 miles is in Massachusetts. Average flow at the USGS gage in West Deerfield for the period from 1940 to 1957 was 1,221 cubic feet per second. The seven day low flow with a ten-year frequency for this gage is 110 cfs.

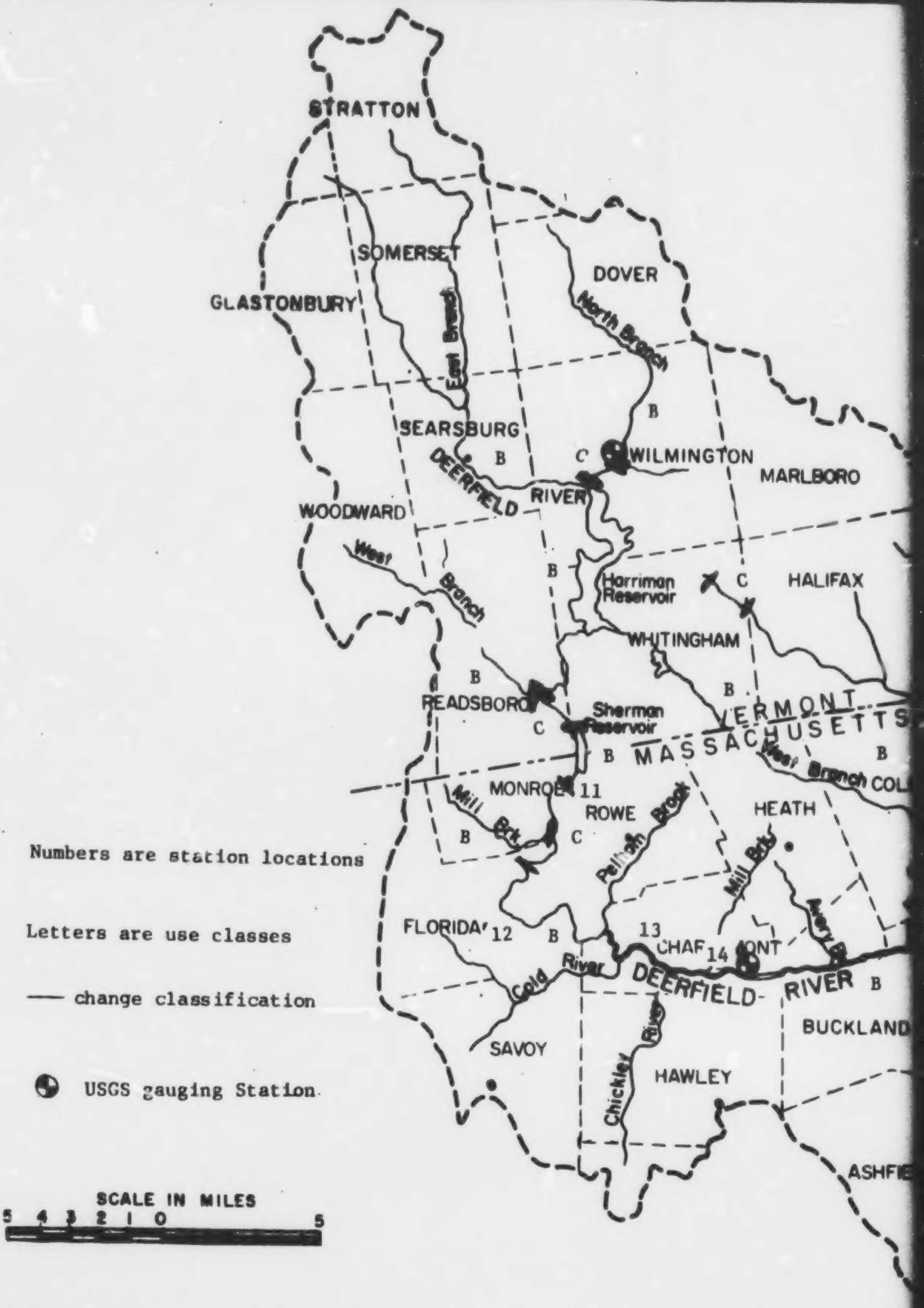
A nuclear power plant located just below the state line in Rowe uses the Deerfield for cooling water. A paper company in Monroe and a steel products manufacturer discharge industrial wastes into the Deerfield. Domestic sewage from the Towns of Monroe, Charlemont, and Deerfield enter the Deerfield while wastes from Colrain, Shelburne, and Buckland are discharged to the North River. Another tributary of the Deerfield - the South River - receives wastes from the Towns of Ashfield and Conway. A private institution discharges domestic wastes to the Deerfield in the Town of Deerfield. The Town of Greenfield operates a sewage treatment plant which provides primary treatment. The plant effluent is discharged to the Green River, half a mile above its confluence with the Deerfield.

The State of Massachusetts performed a sampling survey on those portions of the Deerfield and its tributaries within its boundaries in 1965. The existing data on the Vermont sections of the Deerfield and its tributaries is of 1950's vintage and for the purpose of this section, is considered obsolete. Map 7.2 shows the location of the Deerfield River sampling stations used in the reconnaissance.

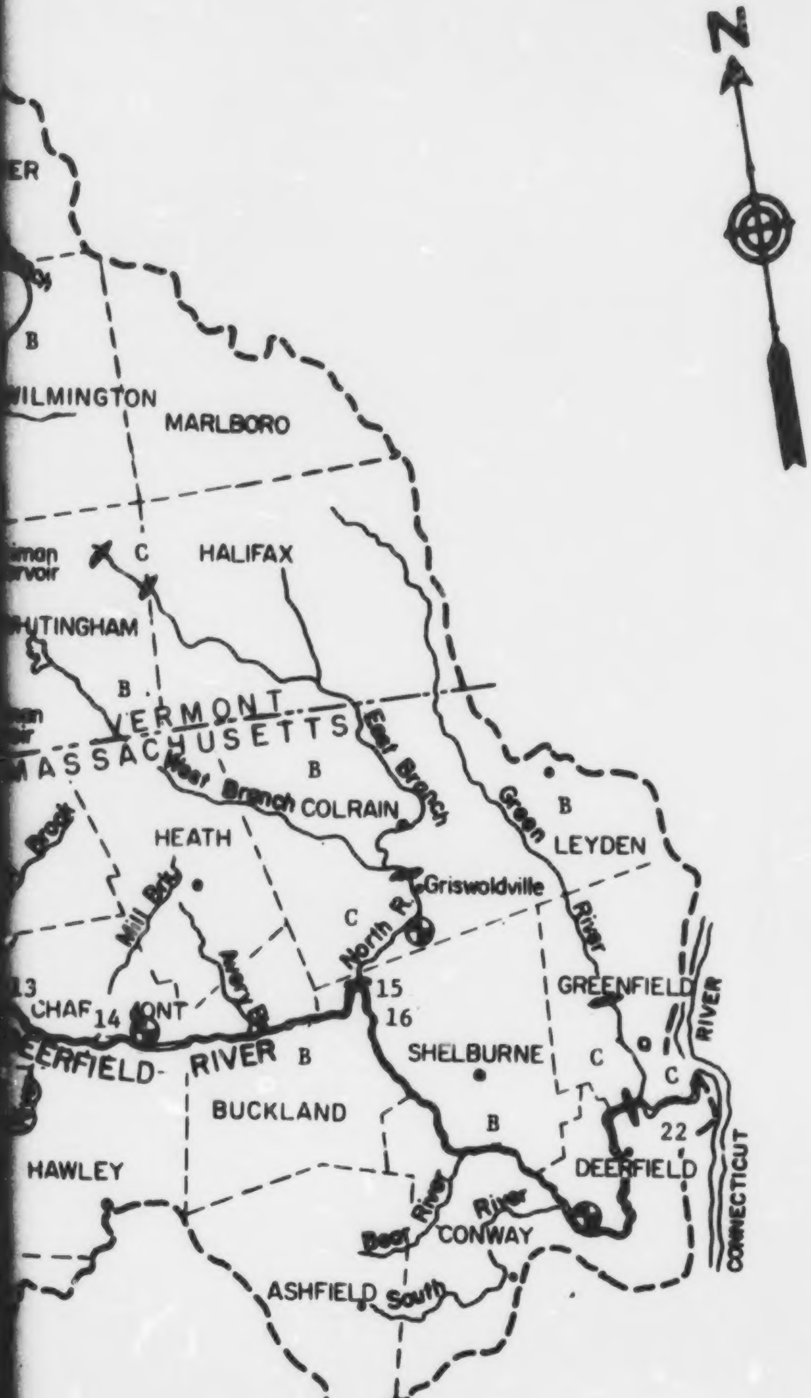
Graphs 7.2 (a-f) show how selected parameter values change as one travels up the tributary. The average flow during the study was about 500 cfs.

According to the graphs, dissolved oxygen remained well above the class B limits of 5 mg/l at all points sampled on the Deerfield. Coliform counts, however, violated class B standards at all sampling stations except 11 and 12. Sharp increases in BOD, alkalinity, suspended solids and coliforms occurred after Station 15. This is due primarily to the influence of the Green River.

There are only four sections of the Deerfield River Basin in Massachusetts that are classified other than B. These sections indicated on the map, are the lower portion of the Deerfield after the confluence of the Green River, the lower portion of the Green River, the lower portion of the North River, and a section of the


STRATTON
SOMERSET
DOVER
GLASTONBURY
East Branch
North Branch
SEARSBURG
B
C
WILMINGTON
MARLBORO
DEERFIELD RIVER
WOODWARD
West Branch
B
Harriman Reservoir
C
HALIFAX
WHITINGHAM
B
READSBORO
B
Sherman Reservoir
C
VERMONT
MASSACHUSETTS
B
West Branch
COL
B
MONROE
11
Mill Brk
ROWE
Pelham Brook
HEATH
B
C
Mill Brk
Avery Br
FLORIDA
12
B
13
CHARLEMONT
14
Cold River
DEERFIELD RIVER
B
BUCKLAND
SAVOY
Chickley River
HAWLEY
ASHFIE
Numbers are station locations
Letters are use classes
— change classification
USGS gauging Station
SCALE IN MILES
5 4 3 2 1 0 5

A


N
ER
B
WILMINGTON
MARLBORO
C
HALIFAX
WHITINGHAM
B
VERMONT
MASSACHUSETTS
B
West Branch
East Branch
COLRAIN
Green River
B
LEYDEN
HEATH
Mill Brk
Griswoldville
C
North R.
13
CHAF
14
MONT
15
16
GREENFIELD
RIVER
DEERFIELD
RIVER
B
SHELBURNE
C
C
BUCKLAND
B
22
HAWLEY
DEERFIELD
Bear River
River
CONWAY
CONNECTICUT
ASHFIELD
South

B

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY
Deerfield River Basin
Map 7.2

Preceding page blank

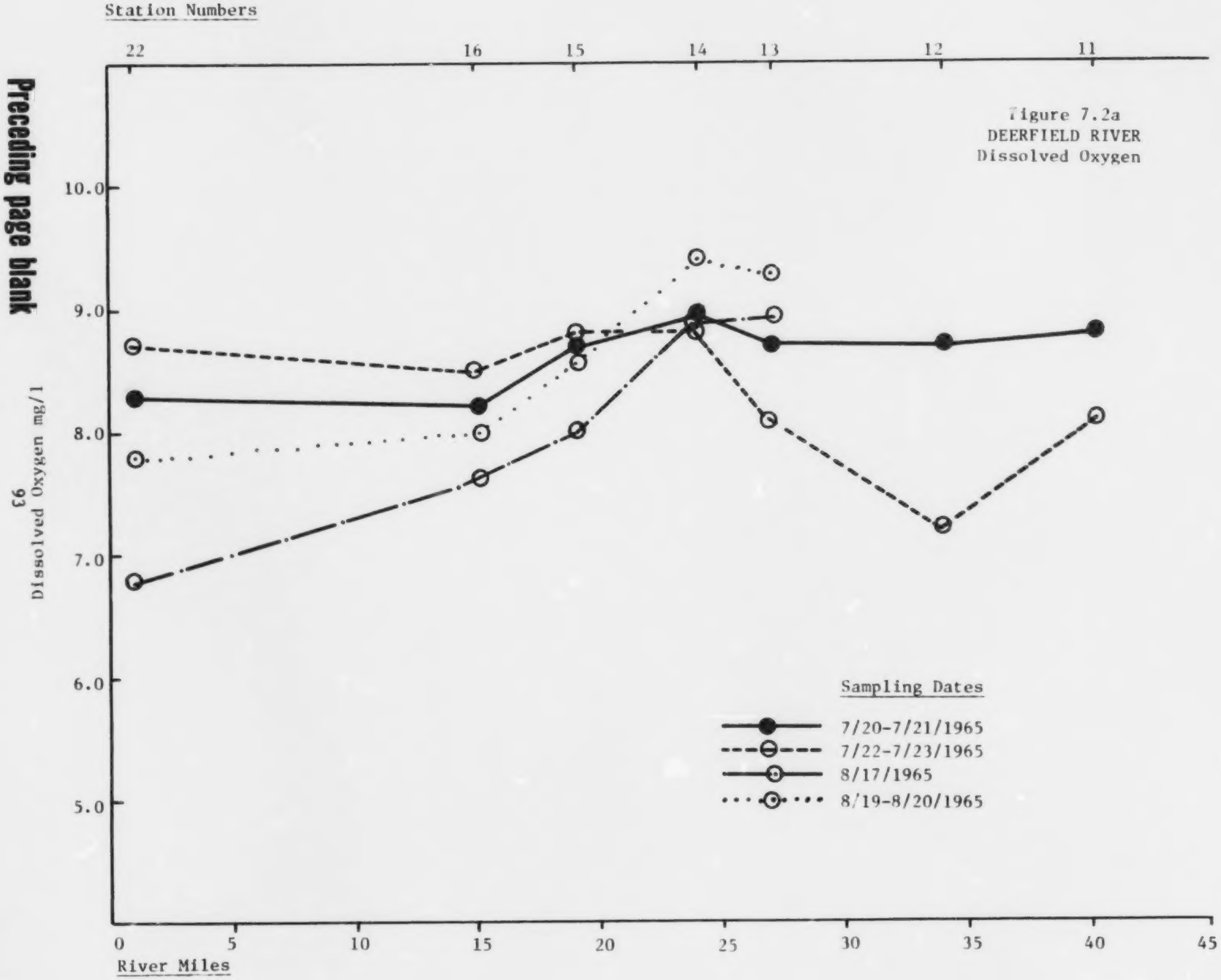


Figure 7.2a
DEERFIELD RIVER
Dissolved Oxygen

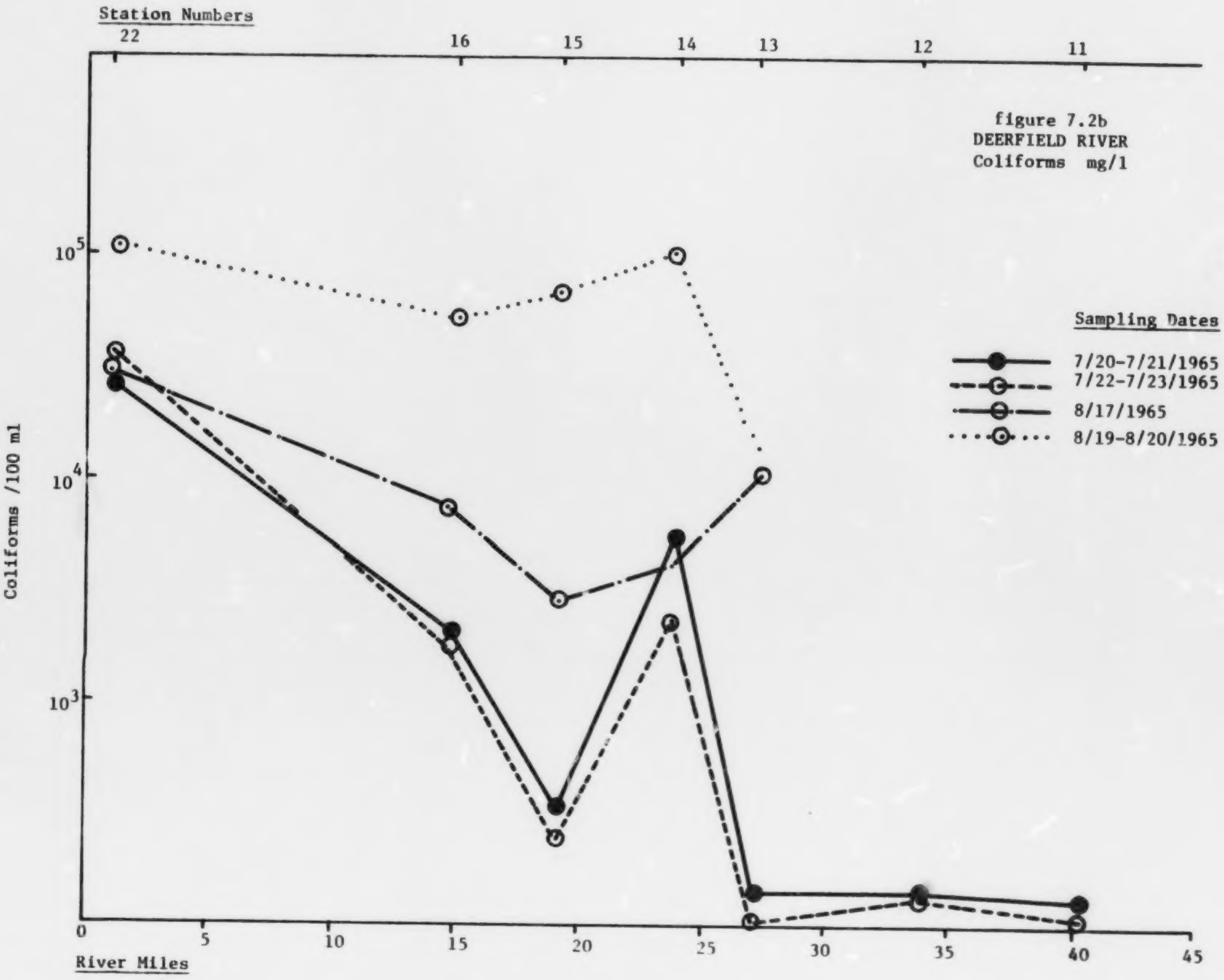


figure 7.2b
DEERFIELD RIVER
Coliforms mg/1

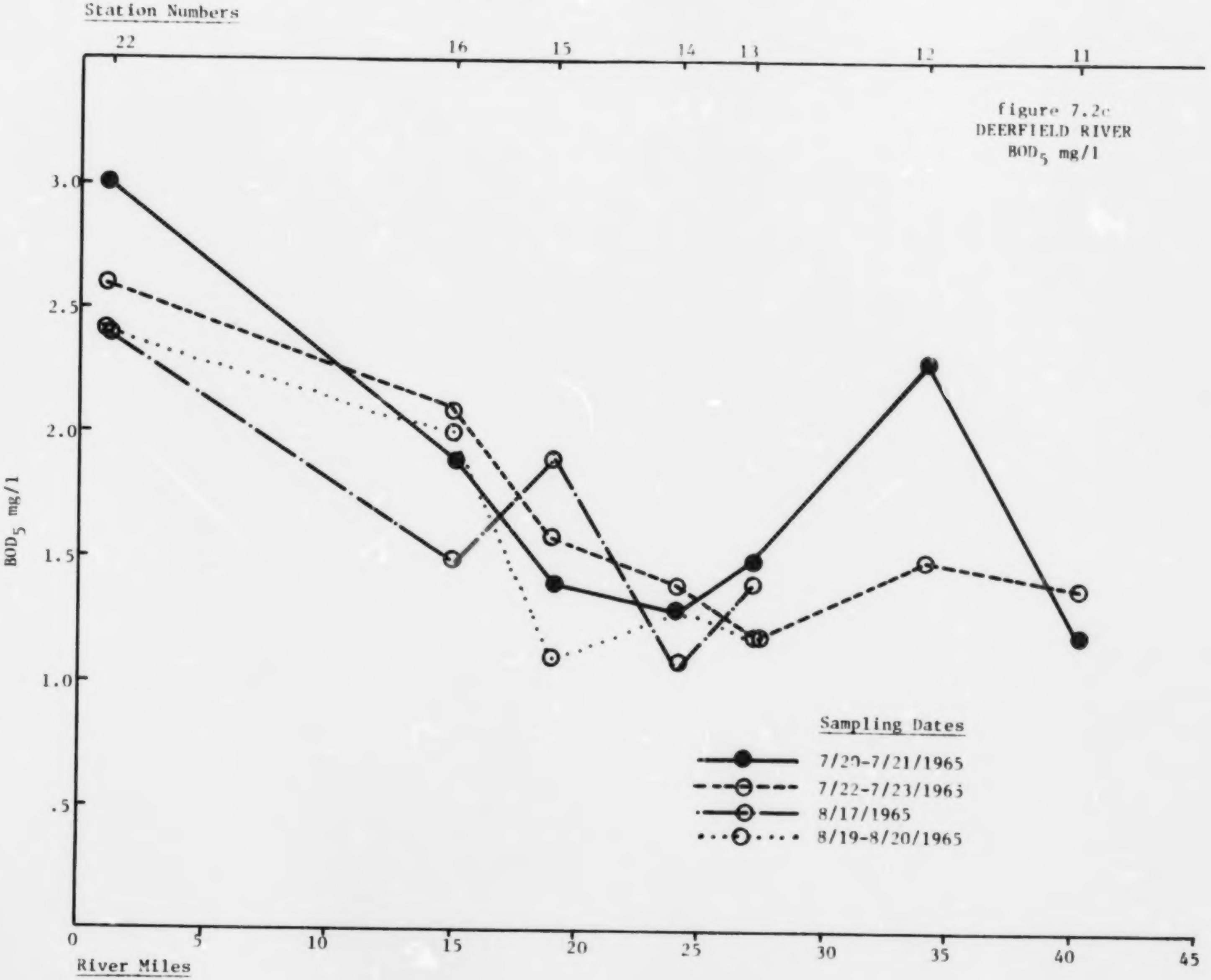


figure 7.2c
DEERFIELD RIVER
BOD_5 mg/l

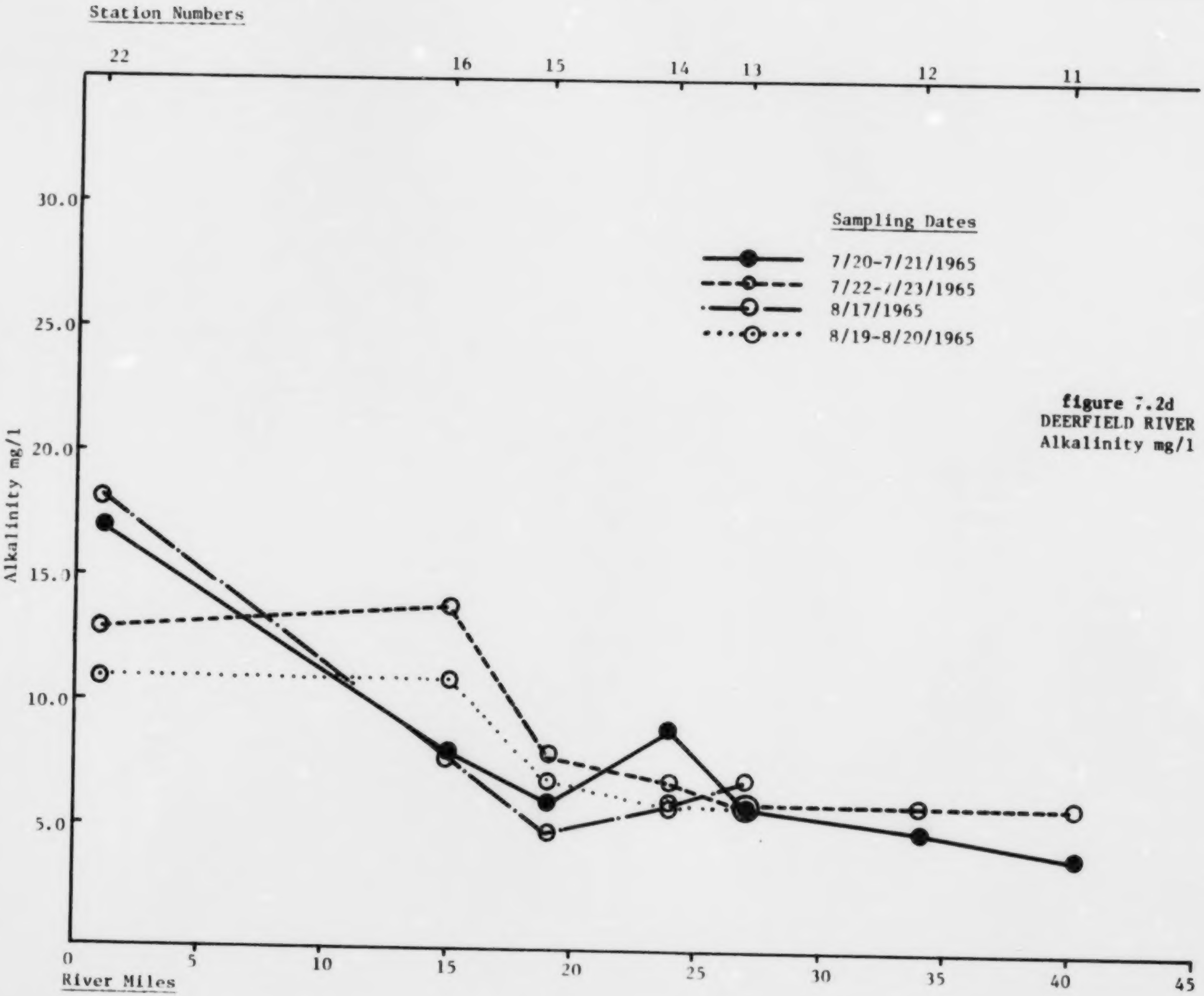


figure 7.2d
DEERFIELD RIVER
Alkalinity mg/1

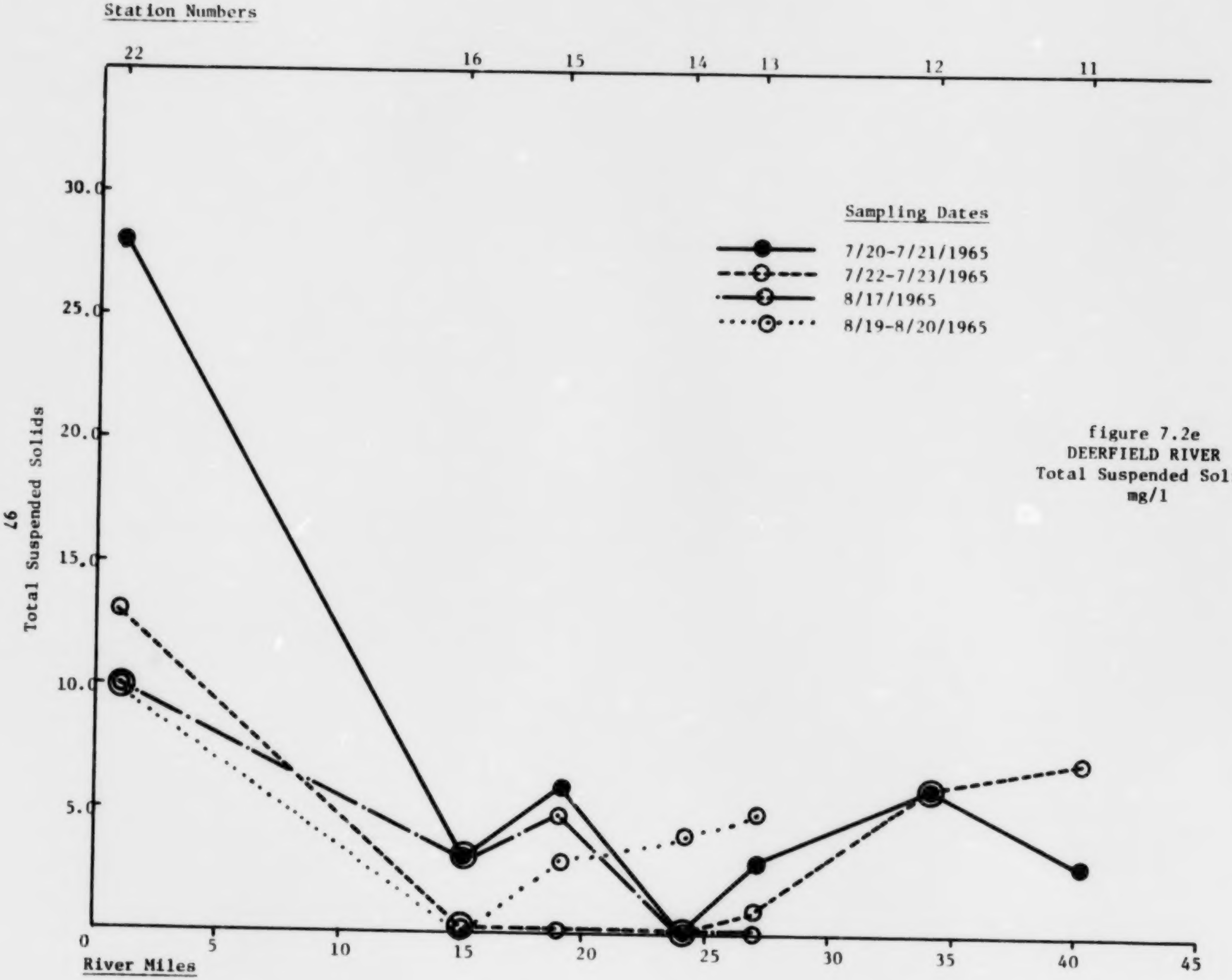


figure 7.2e
DEERFIELD RIVER
Total Suspended Solids
mg/1

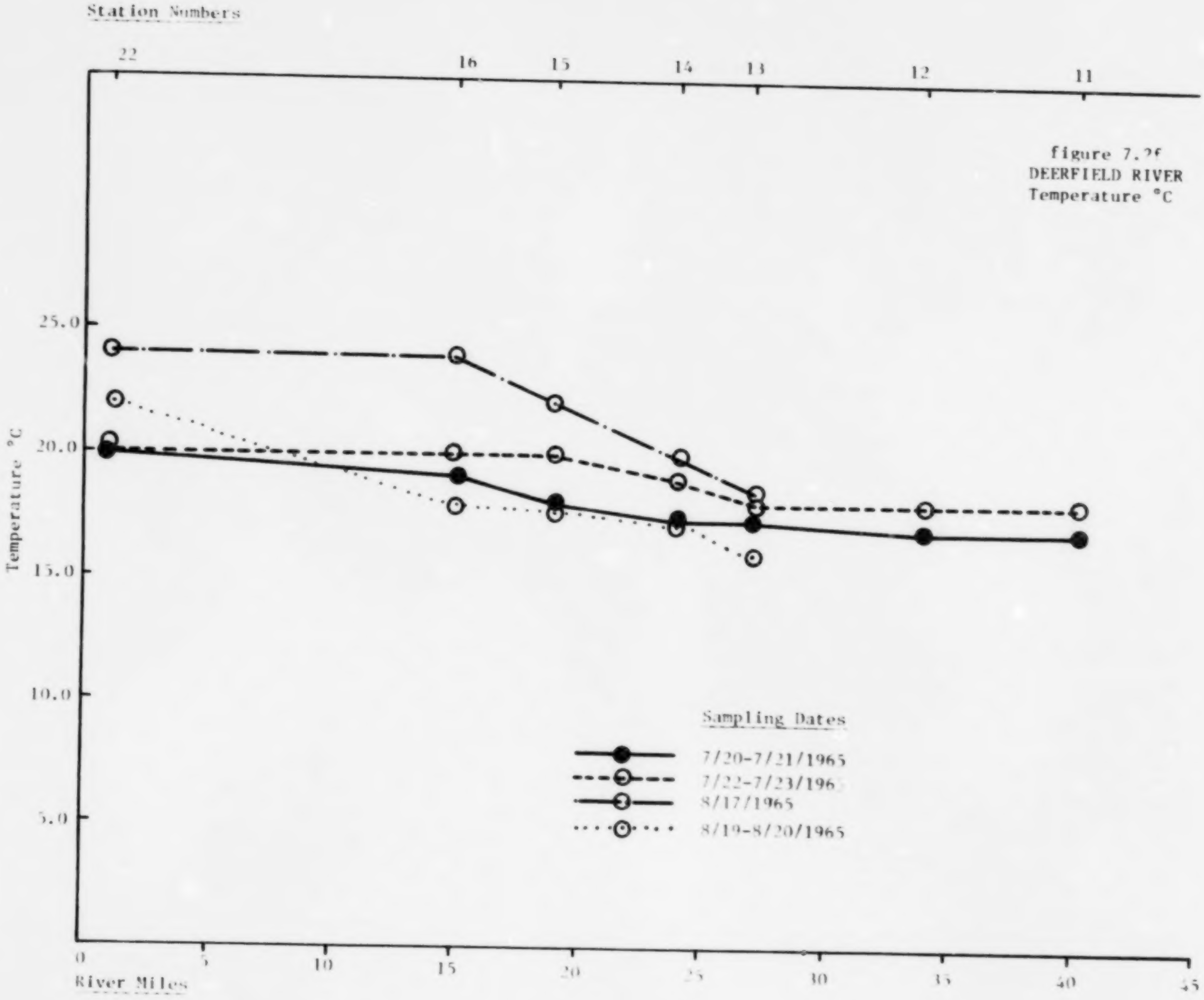
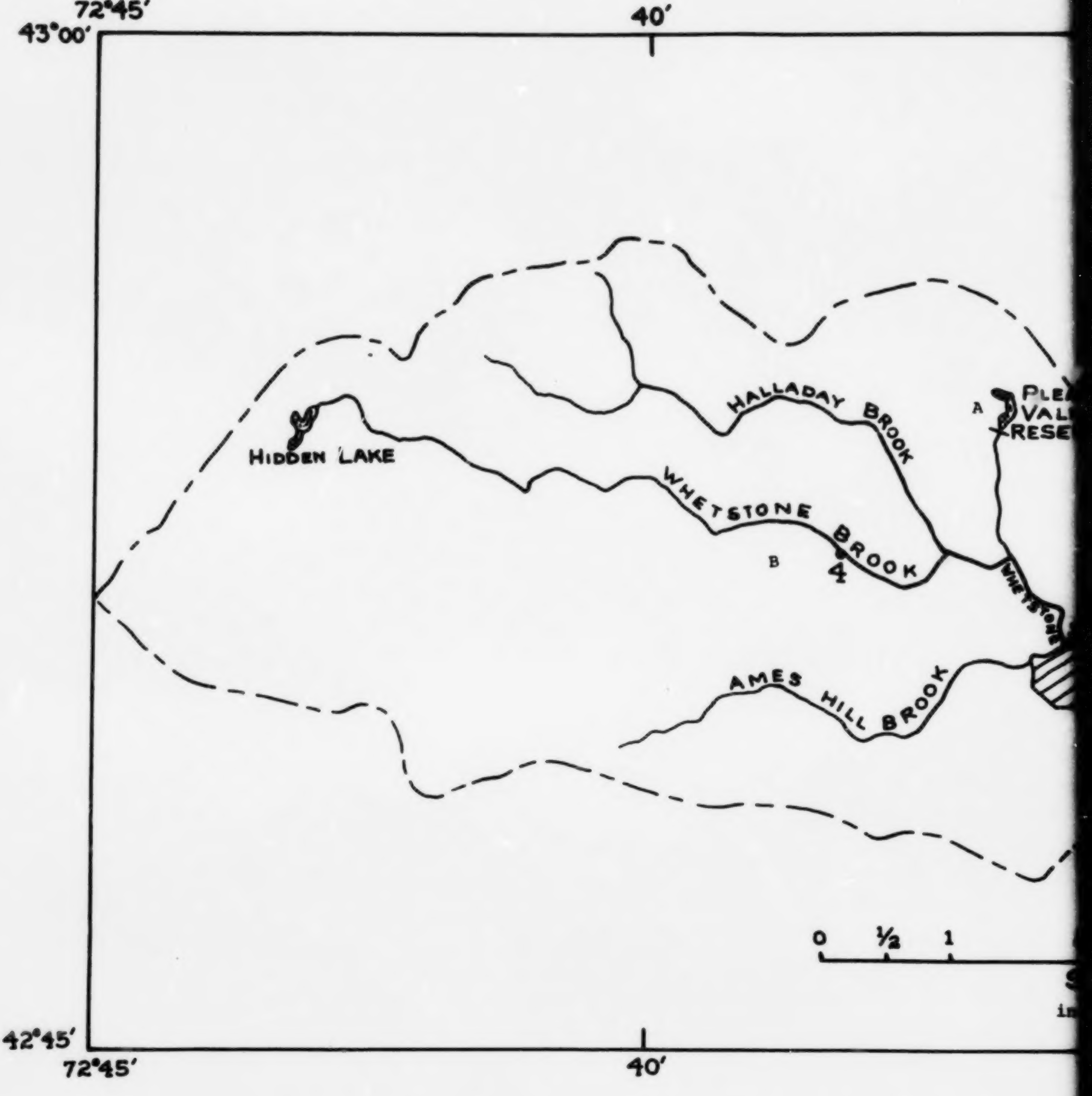


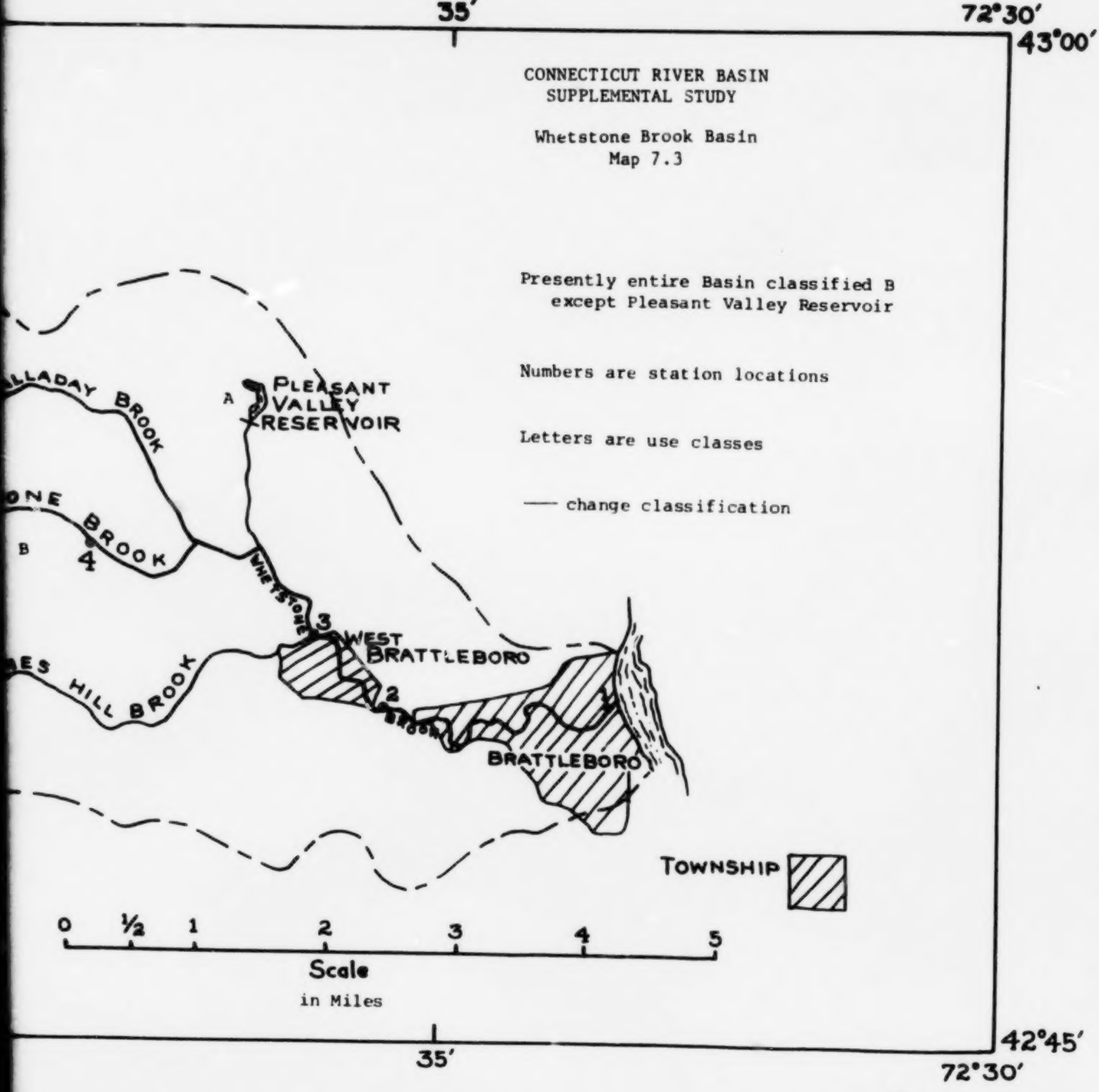
figure 7.2f
DEERFIELD RIVER
Temperature °C


72°45'
40'
43°00'
HALLADAY BROOK
A
PLEA
VAL
RESE
HIDDEN LAKE
WHETSTONE BROOK
B
4
WHETSTONE
AMES HILL BROOK
0
½
1
S
in
42°45'
72°45'
40'

A

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY

Whetstone Brook Basin
Map 7.3


35'
72°30'
43°00'
LLADAY BROOK
A
PLEASANT VALLEY RESERVOIR
ONE BROOK
B
4
WHETSTONE
3
WEST BRATTLEBORO
2
BROOK
ES HILL BROOK
BRATTLEBORO
TOWNSHIP
0
½
1
2
3
4
5
Scale
in Miles
35'
42°45'
72°30'

Presently entire Basin classified B
except Pleasant Valley Reservoir

Numbers are station locations

Letters are use classes

—— change classification

B

Deerfield near Monroe. These lower classifications are due to discharges occurring in these areas. The Greenfield River Treatment plant mentioned earlier discharges 3.2 MGD of domestic primary effluent to the Green River; the Deerfield Glassine Company, the paper company at Monroe, releases 4.6 MGD of effluent at Monroe Bridge, and the North River is subject to .85 MGD of textile effluent from the Kendall Fibre Products Division Treatment Plant. These major discharges plus the others mentioned in Appendix D of the Comprehensive Study and the Bureau of Sport Fisheries and Wildlife Section all combine to tax the stream's natural assimilative capacity.

Data recorded on the North River and Green River indicate that effluent discharges are severly taxing the streams' waste carrying capacity. Samples taken on the North River indicate significantly higher concentrations of BOD, suspended solids, COD, and alkalinity were found. However, the dissolved oxygen concentrations were much lower than those found on the Deerfield. The pH value recorded at the station on the North River was the highest recorded in the survey being 9.25, while the overall average for the entire tributary system was around 7.0. The North River sampling station also recorded the highest levels of BOD, COD, and alkalinity. The Green River exhibited high concentrations in BOD, suspended solids, COD, coliforms and alkalinity with the concentrations of suspended solids and coliforms being the highest recorded for the entire tributary system. The Green River also recorded the lowest average dissolved oxygen concentrations with the minimum concentration being less than 1 mg/l.

Finally, map 7.2 indicates the Vermont classifications for those portions of the Green, North and Deerfield Rivers in the State of Vermont. However, there is no recent data available to explain the classifications.

With the standards' compliance goal in 1977, it is expected that many of the reaches now in violation of their classifications will be upgraded to meet presently proposed standards.

7.3 The Whetstone Brook Basin

Whetstone Brook is a small tributary entering the Connecticut River at the Town of Brattleboro, Vermont. It originates above Hidden Lake in Marlboro, Vermont and flows 11 miles to its confluence with the Connecticut. The watershed covers 28 square miles of 17,900 acres. Whetstone Brook has three main tributaries entering it; Halladay Brook, Ames Hill Brook, and the stream coming from the Pleasant Valley Reservoir. There are two small dams in Brattleboro. The flow for the Whetstone varies with elevation. At 1,330 feet the flow is 3 cfs; at 540 feet it is 5 cfs; and in Halladay Brook at 680 feet the flow is estimated to be 8 cfs.

Preceding page blank

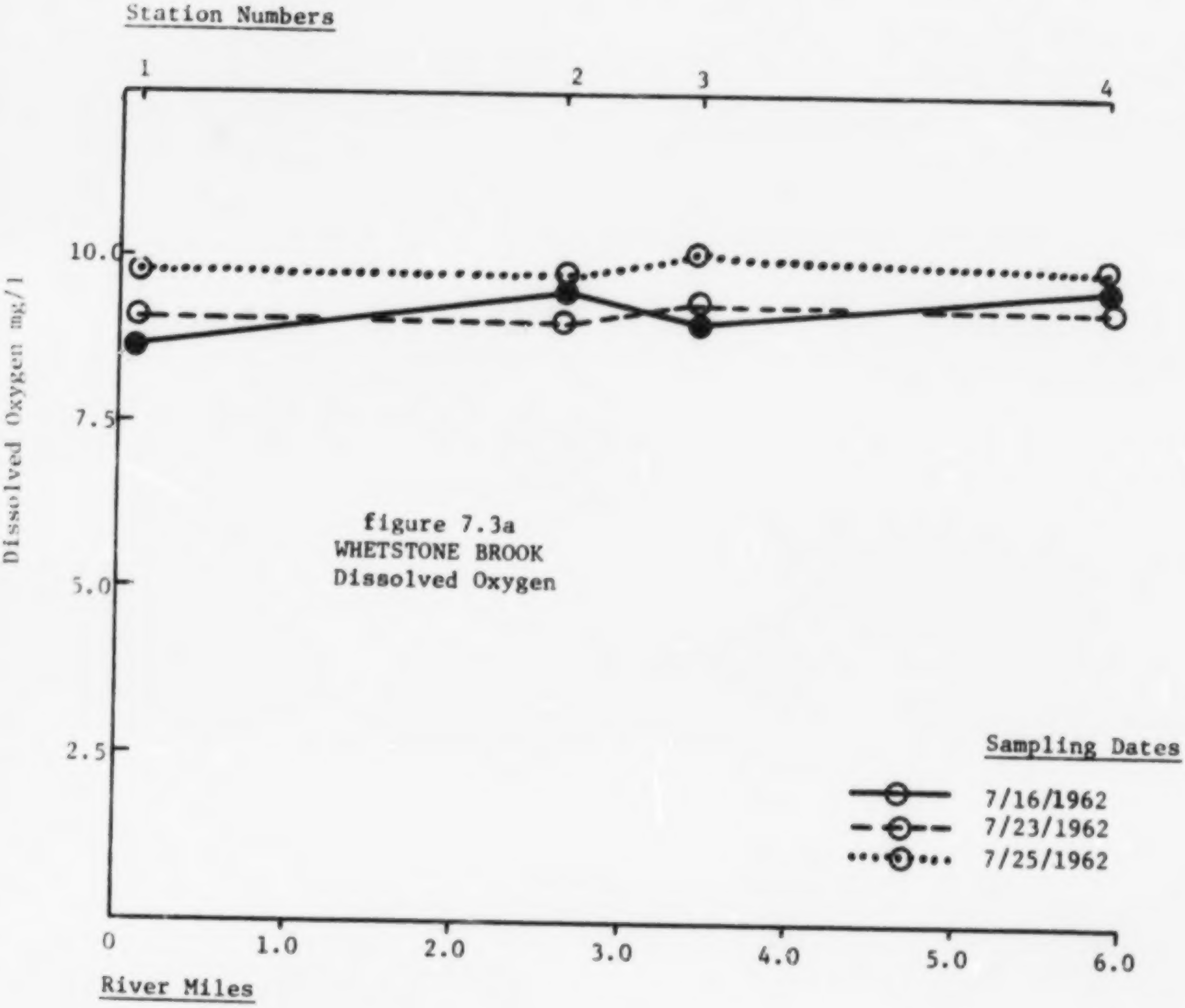


figure 7.3a
WHETSTONE BROOK
Dissolved Oxygen

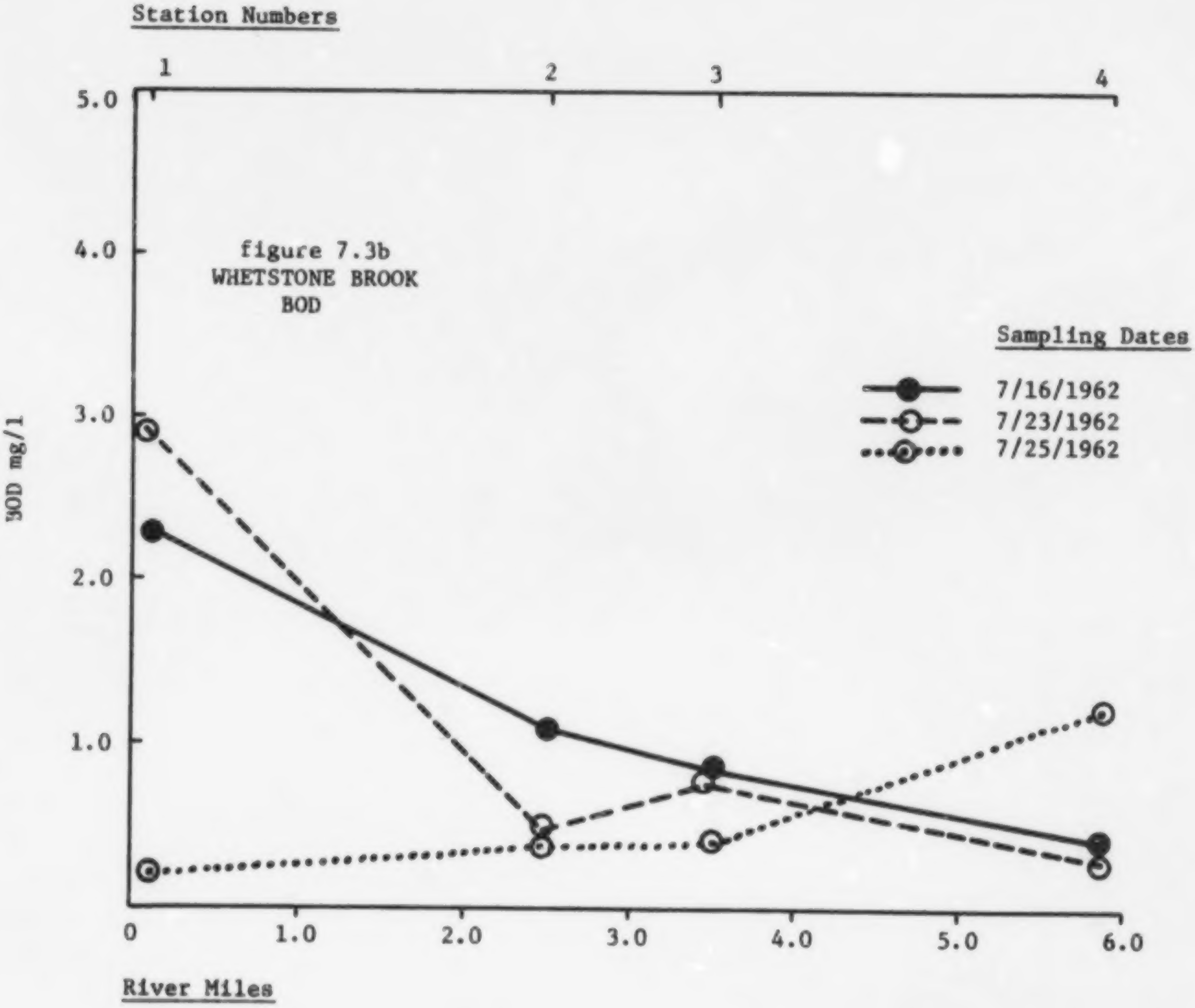


figure 7.3b
WHETSTONE BROOK
BOD

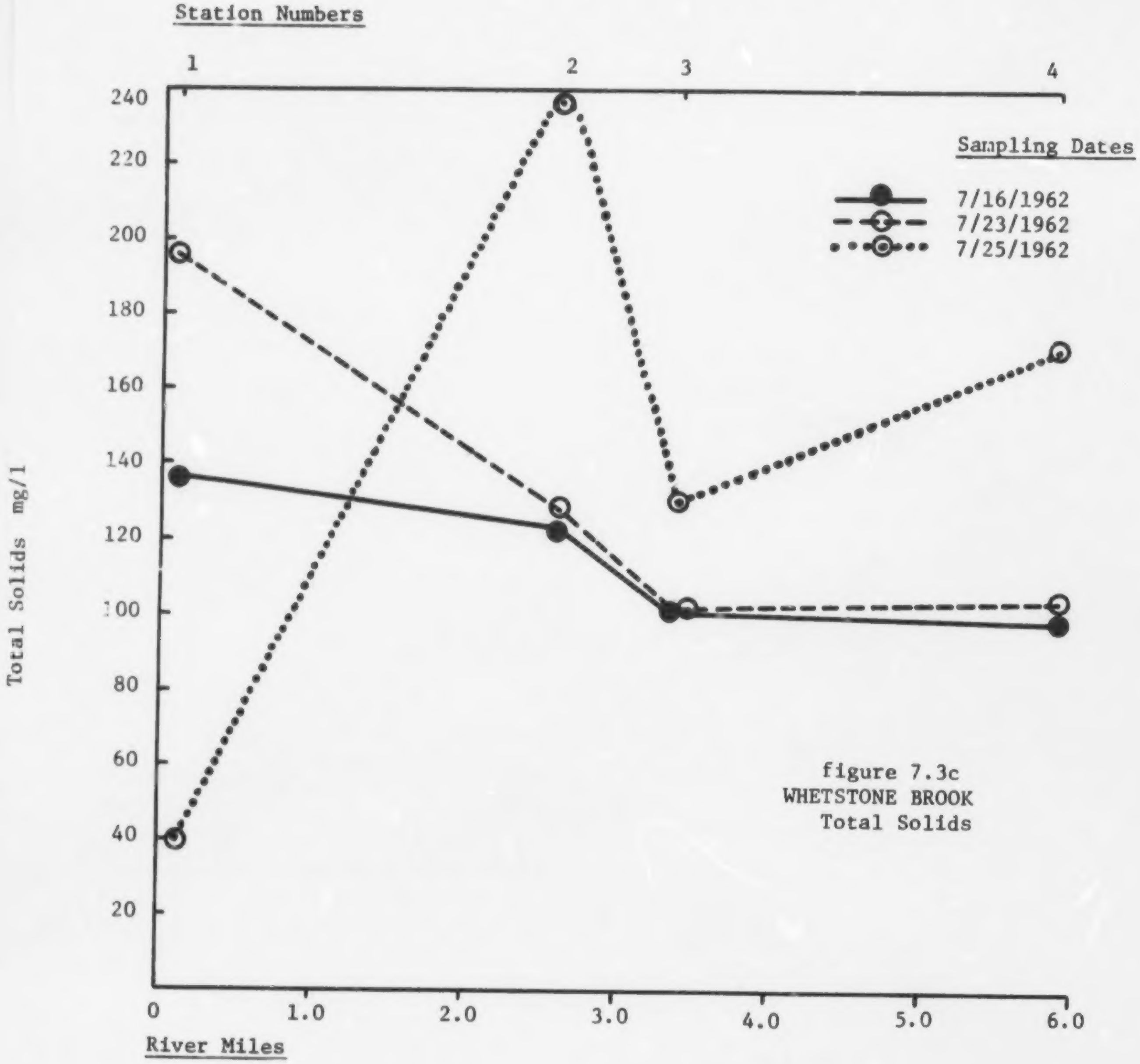


figure 7.3c
WHETSTONE BROOK
Total Solids

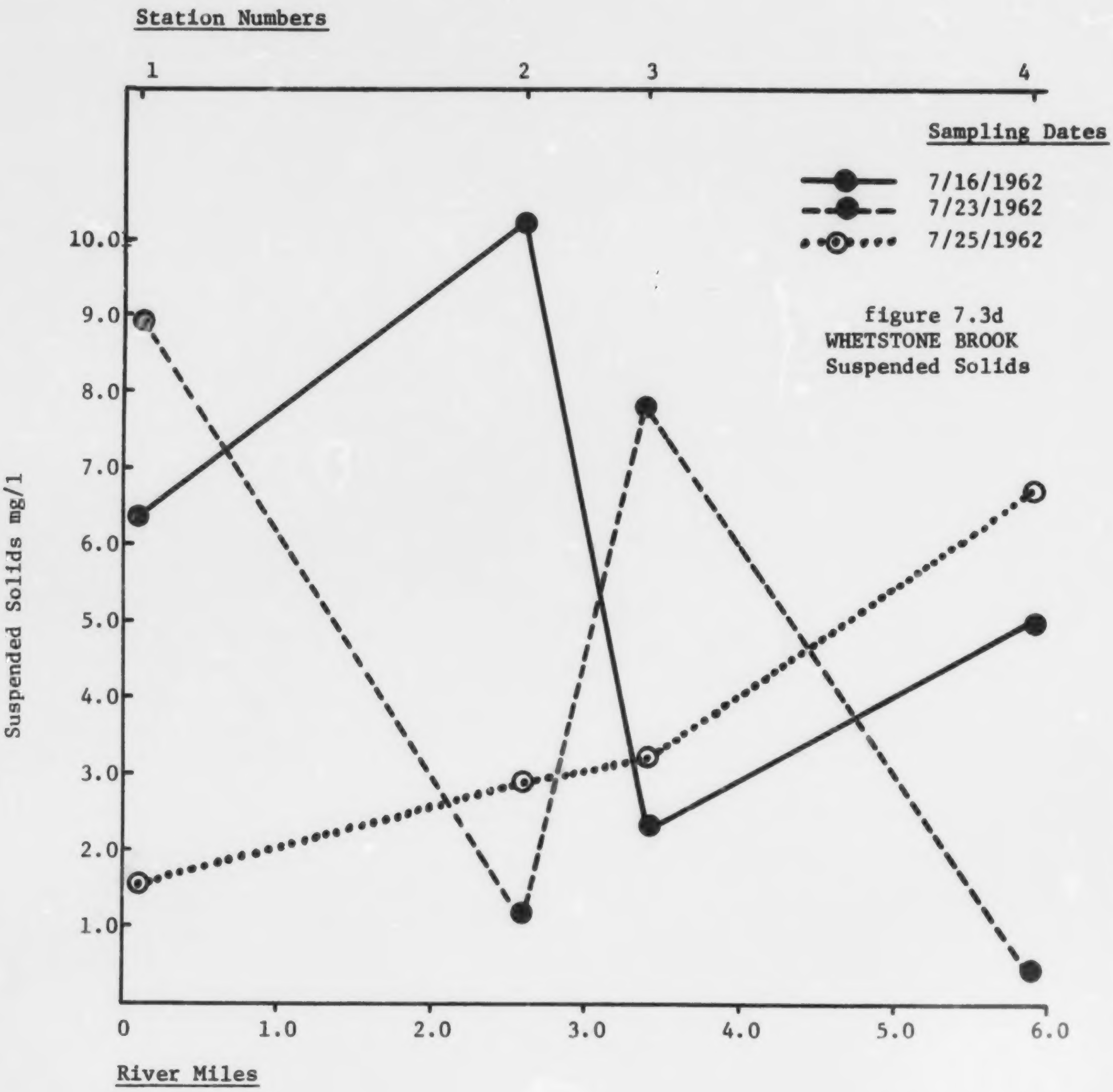


figure 7.3d
WHETSTONE BROOK
Suspended Solids

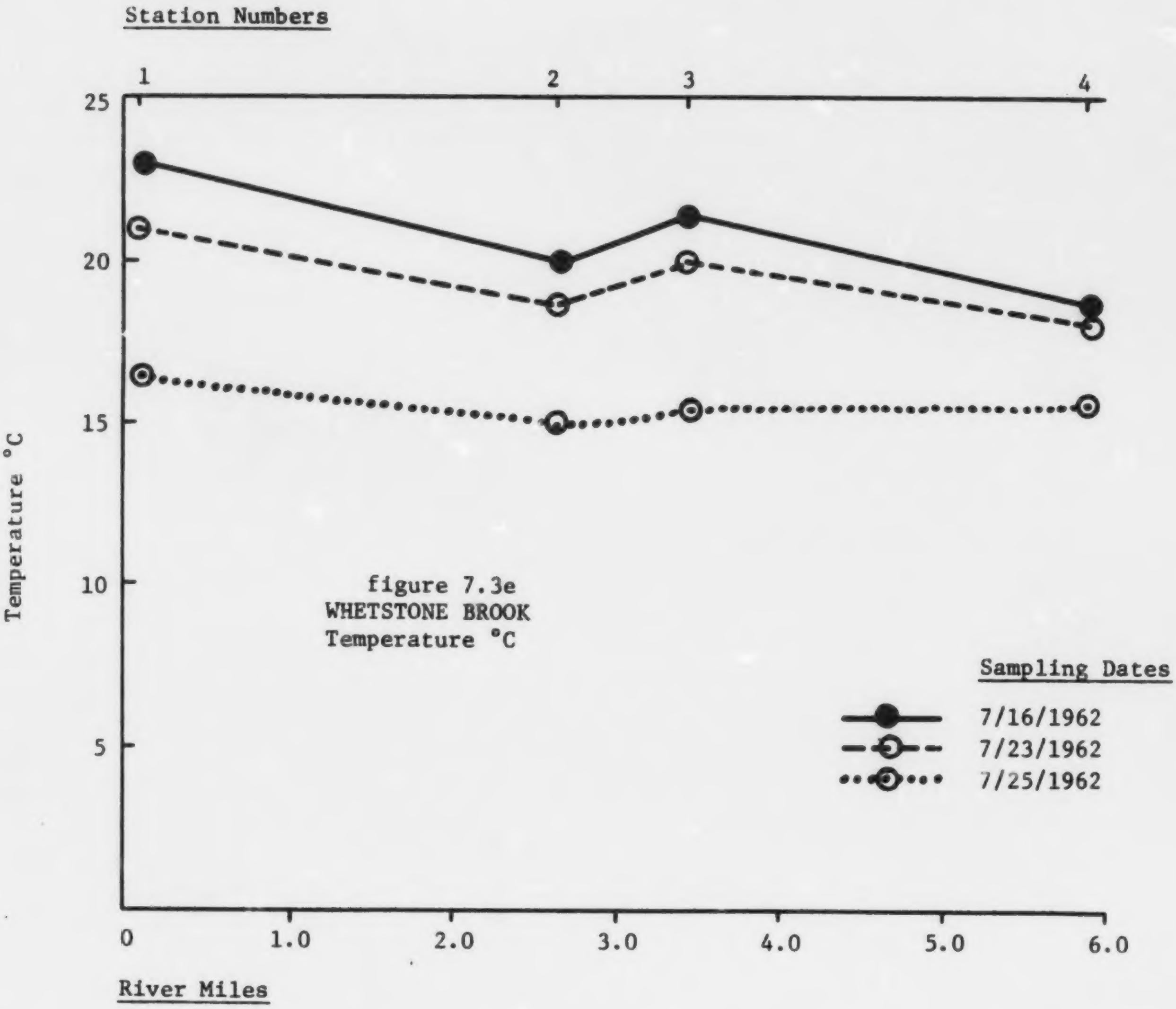


figure 7.3e
WHETSTONE BROOK
Temperature °C

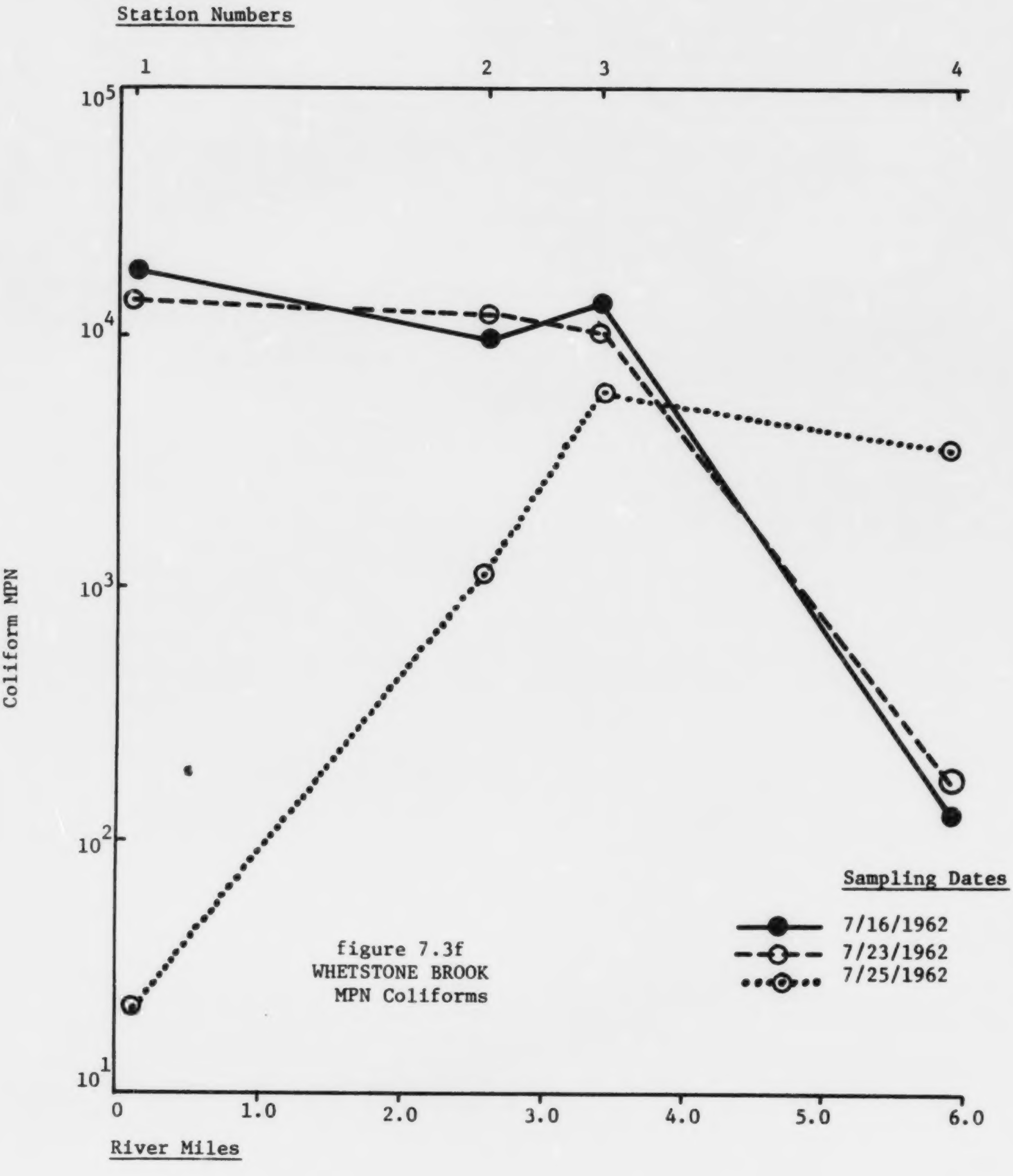


figure 7.3f
WHETSTONE BROOK
MPN Coliforms

The Whetstone supplies no significant floodwater contribution to the Connecticut River. However, its mountain stream flashflood character does pose localized flood problems for the Town of Brattleboro.

The State of Vermont has only four sampling stations on the Whetstone. These are indicated on Map 7.3 Graphs 7.3 (a-f) indicate the changes in water quality as one moves from the populous areas of Brattleboro and West Brattleboro to the western mountainous areas.

The dissolved oxygen concentration for Whetstone Brook was always above the class A, Type I limit set by the State of Vermont. This limit requires 7 mg/l D.O. near spawning areas. This is significant because the Whetstone is considered to have a high potential value as a trout stream.

The BOD is very low in the rural areas of the stream, but the effects of Brattleboro are illustrated by the significant increase in BOD at Station 1. The total and suspended solids concentrations vary and little correlation can be observed. Temperature is fairly constant, but the coliform concentrations generally exhibit lower concentrations at Station 4 with significantly higher concentrations closer to Station 1. The discrepancies in the July 25th sampling are not readily explainable. In no case does the coliform count meet the class B standards since greater than 500 coliforms per 100 ml is exceeded at every station sampled at least once. Only at Station 4 is the possibility of meeting class C standards possible, and this depends on what percentage of the coliforms measured is fecal.

The Whetstone offers a good example of the effect that population centers can have on streams. Significant differences in most of the parameters can be noted between the upstream stations and those stations occurring after West Brattleboro. The high concentrations in coliform MPN along the entire river can be due to animal; i.e., cattle contamination or contamination from houses and trailer parks along the brook. However, a significant increase in coliform concentration does occur after passage through West Brattleboro.

The significant rise occurring after West Brattleboro in BOD, solids, coliforms and turbidity (not shown) indicates the presence of a significant effluent discharge at West Brattleboro. Since there is no treatment plant or major industries in West Brattleboro, it is assumed that this may be an untreated domestic discharge. With the enforcement of the 1972 Amendments, it is expected that this peak will be significantly reduced.

The entire Whetstone Brook is presently classified B standard except in the Pleasant Valley Reservoir which is classified A. By 1977, all standards will have to be met. This means that a treatment plant may be required at West Brattleboro. However, Vermont standards require that a stretch of river below any treatment plant discharge be reclassified as C, to allow a bacterial safety zone, whenever a treatment plant is established.

7.4 The White River Basin

The White River, with a drainage area of about 712 square miles all in Vermont, rises on the northeast slope of Battell Mountain in the Town of Ripton, Vermont, and flows east five miles to Granville, then south 19 miles through Hancock and Rochester to Stockbridge where it turns and follows a northeasterly course nine miles to Bethel. It then flows easterly seven miles to South Royalton and finally southeasterly 18 miles through the villages of Sharon and Hartford, to its confluence with the Connecticut River at White River Junction, Vermont. This river has a total length of about 58 miles, and a total fall of about 2,170 feet of which 1,600 feet are in its upper nine miles. The three principal tributaries of the White River are the First, Second and Third Branches, which are described below:

(1) The First Branch rises in the southwestern part of the Town of Washington and flows in a southerly direction for a distance of 21 miles to its confluence with the White River at South Royalton. It has a total fall of about 880 feet and a drainage area of 103 square miles.

(2) The Second Branch rises above Staples Pond in the Town of Williamstown and flows southerly 25 miles to its mouth at the White River at North Royalton. It has a total fall of about 430 feet and a drainage area of 73 square miles.

(3) The Third Branch rises in Roxbury and flows in a southeasterly direction about 26 miles to join the White River at Bethel. It has a drainage area of 136 miles and a total fall of about 470 feet.

Map 7.4 indicates some of the sampling points established by Vermont and used to develop a water quality reconnaissance.

As of July, 1971, all waters of the White River were classified B. However, under the new standards revisions, any water immediately below a treatment plant will be reclassified C for a sufficient length to provide a bacterial safety zone for public health.

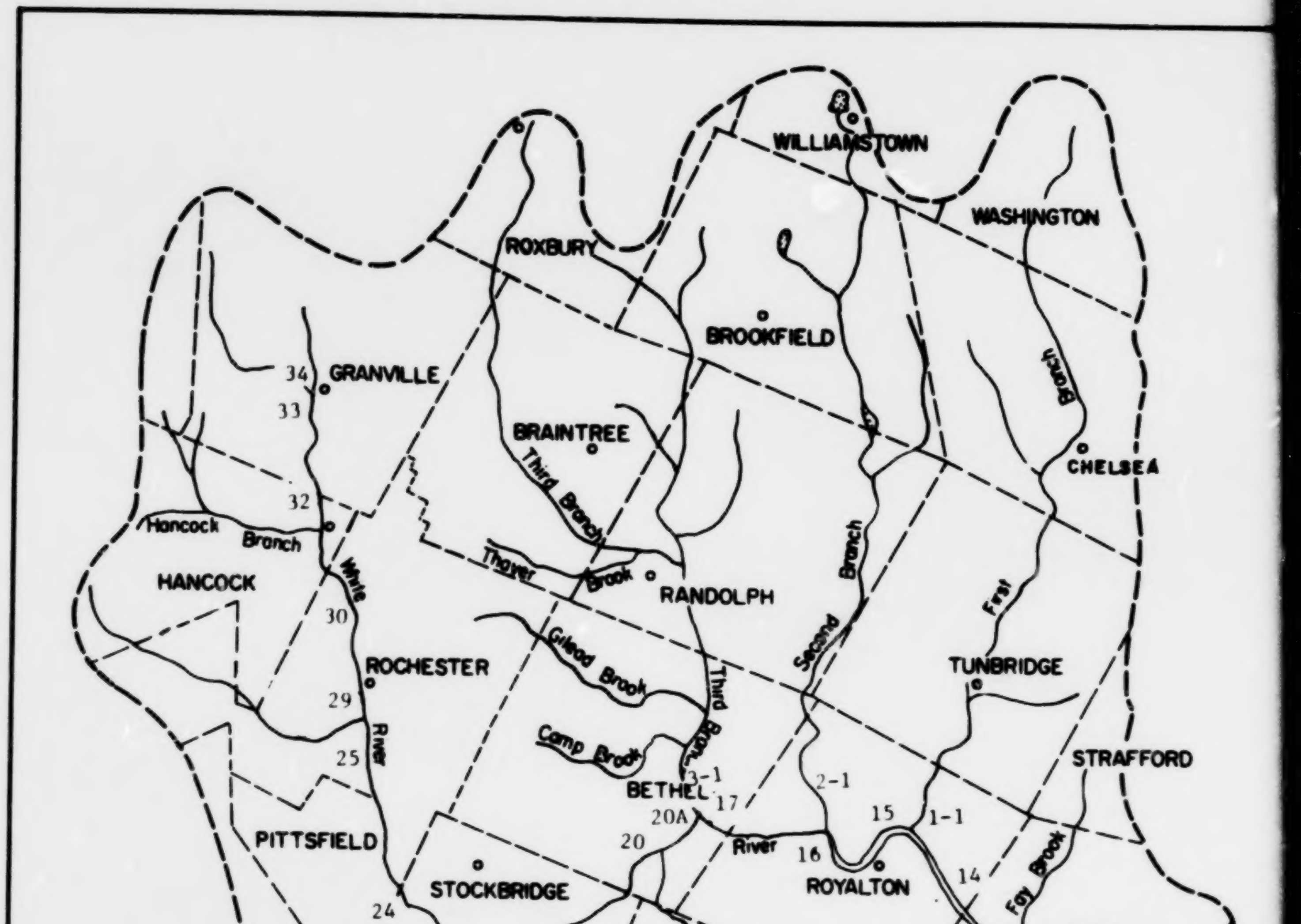
Graphs 7.4 (a-d) illustrate the trends exhibited in several water quality parameters as one travels up the mainstem. The information regarding the parameters was synthesized from the data taken on the White River in 1964.

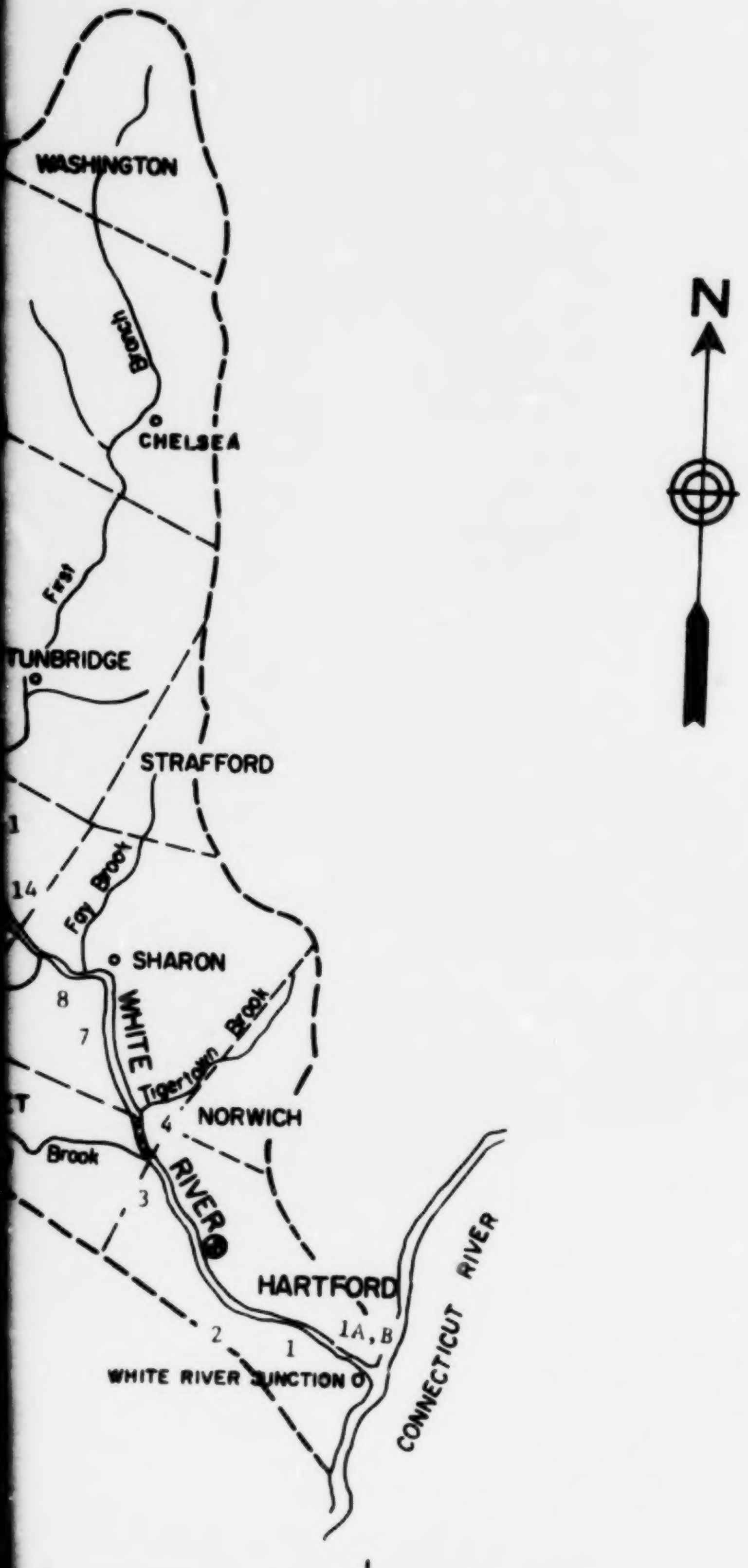
The dissolved oxygen profile of the White River at all points measured was always above 7.0 mg/l. This DO level meets the specifications established for a Type I water which sustains natural populations of brook trout, salmon, rainbow trout, and brown trout. The depressions at Stations 2, 3, 17 and 33 indicate the possible presence of some discharges which place a demand on the streams dissolved oxygen. Stations 2 and 3 show the effect of West Hartford. The depression at Station 17 could indicate the effects of the domestic wastes from Bethel and the depression at Station 33 could show the effects of the wood waste effluent entering the river around Granville. In spite of these waste load demands, the dissolved oxygen concentration always remained about 7.0, as was previously noted.

Upon examining the BOD profile for the White River, one finds a minimal BOD. However, in most instances, the peaks in the BOD curve generally coincide with the depressions in the DO curve. The high concentration of dissolved oxygen along with the minimal influence of the BOD suggests a high rate of reaeration. This is affirmed by the numerous stretches of white water in the White River. The same effects are exhibited in the Passumpsic River and Whetstone Brook.

The alkalinity concentrations, although not applied or illustrated, exhibit a very interesting trend. Prior to the mainstem's confluence with the Third Branch, the alkalinity appears to be relatively stable at low concentrations. With the contributions of higher alkaline waters from the three main branches, the alkalinity profile trends upward reflecting the effects of the three branches' contributions. The mainstem of the White River after the confluences of the three branches tends to stabilize at a higher concentration, thus reflecting the influence of the tributaries. The reason for these high alkalinity contributions is primarily due to geologic terrain. The three branches flow from a region underlain by some metamorphosed limestone deposits principally in the Waits River formation. This would account for the higher alkalinity concentrations. The presence of metamorphosed limestone or marble and the leaching effects of the tributaries is also indicated by the high calcium ion concentrations recorded for the tributaries by the State of Vermont.

The temperature profile for the White River exhibits a natural trend. The high elevated headwaters are colder than the


WILLIAMSTOWN
WASHINGTON
ROXBURY
BROOKFIELD
GRANVILLE
34
33
32
BRAINTREE
Third Branch
Branch
CHELSEA
Hancock
Branch
Hancock Branch
White
HANCOCK
Thayer Brook
RANDOLPH
Second Branch
First
30
ROCHESTER
Gilead Brook
Third Bran.
TUNBRIDGE
29
Camp Brook
STRAFFORD
25
River
3-1
BETHEL
17
2-1
15
1-1
20A
PITTSFIELD
20
River
16
ROYALTON
14
Fay Brook
STOCKBRIDGE
24
SHARON
CHITTENDEN
River
23
White
Locust Creek
8
WHITE
7
Tigertown Brook
POMFRET
4
NORWICH
MENDEN
Deer
BARNARD
Broad Brook
SHERBURNE
RIVER
3
HARTFO
1A
2
1
WHITE RIVER JUNCTION
Numbers are station locations
Presently entire Basin
classified B
USGS Gauging Station
SCALE IN MILES
2
1
0
2


N
WASHINGTON
Branch
CHELSEA
First
TUNBRIDGE
STRAFFORD
1
14
Fay Brook
SHARON
8
7
WHITE
Tigertown Brook
NORWICH
4
T
Brook
RIVER
3
HARTFORD
1A, B
2
1
WHITE RIVER JUNCTION
CONNECTICUT RIVER

B

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY

White River Basin
Map 7.4

Preceding page blank

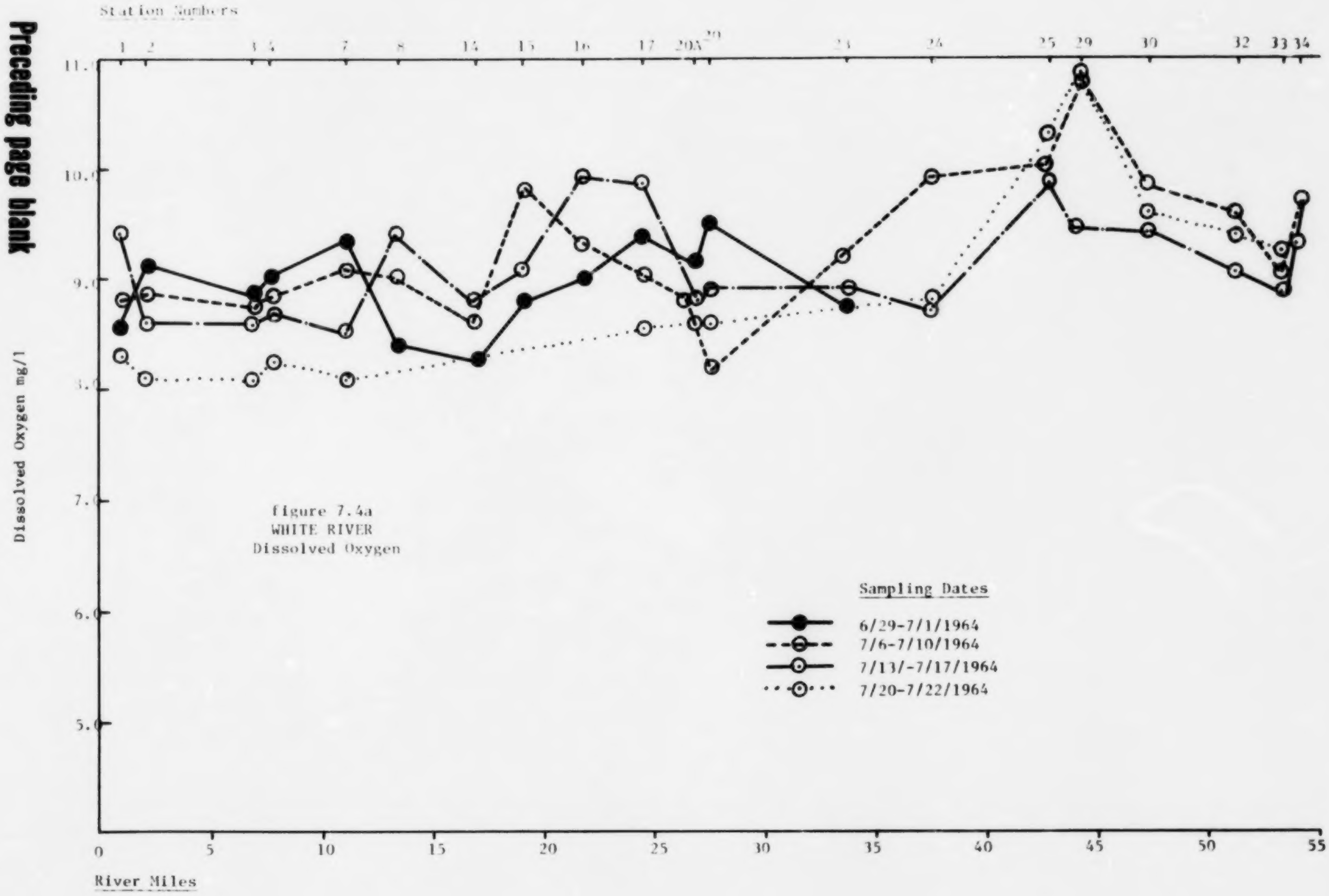


figure 7.4a
WHITE RIVER
Dissolved Oxygen

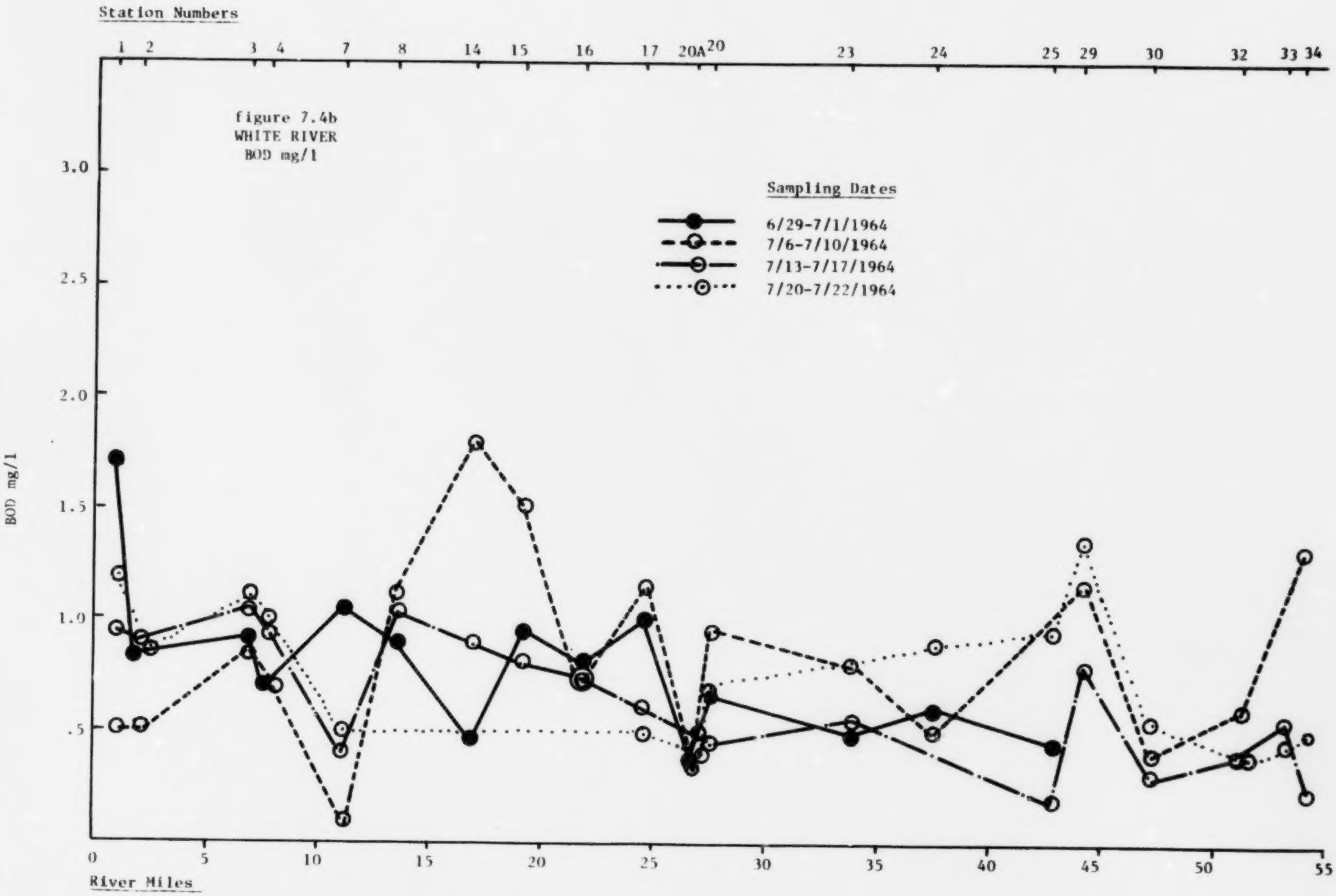


figure 7.4b
WHITE RIVER
BOD mg/1

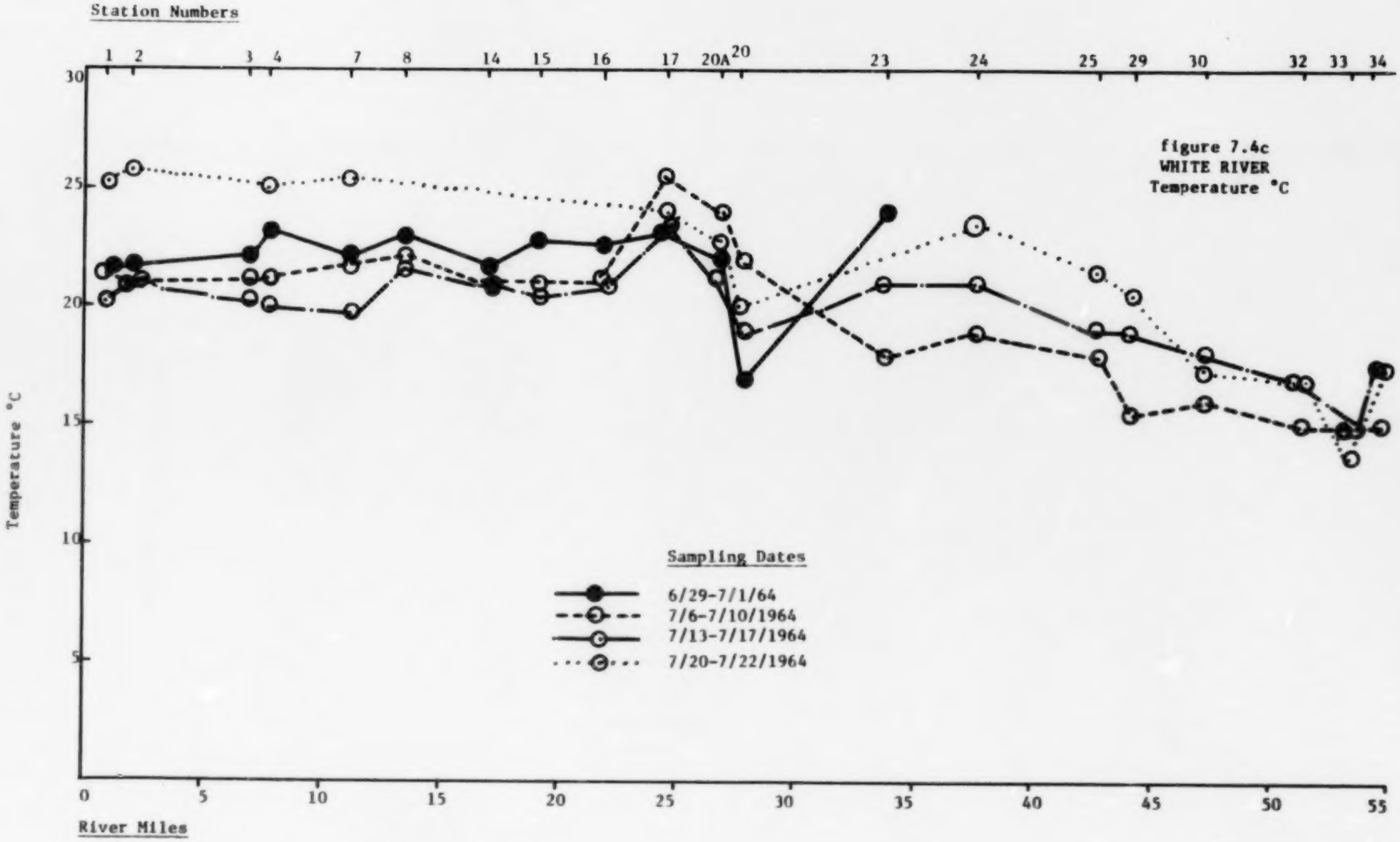


figure 7.4c
WHITE RIVER
Temperature °C

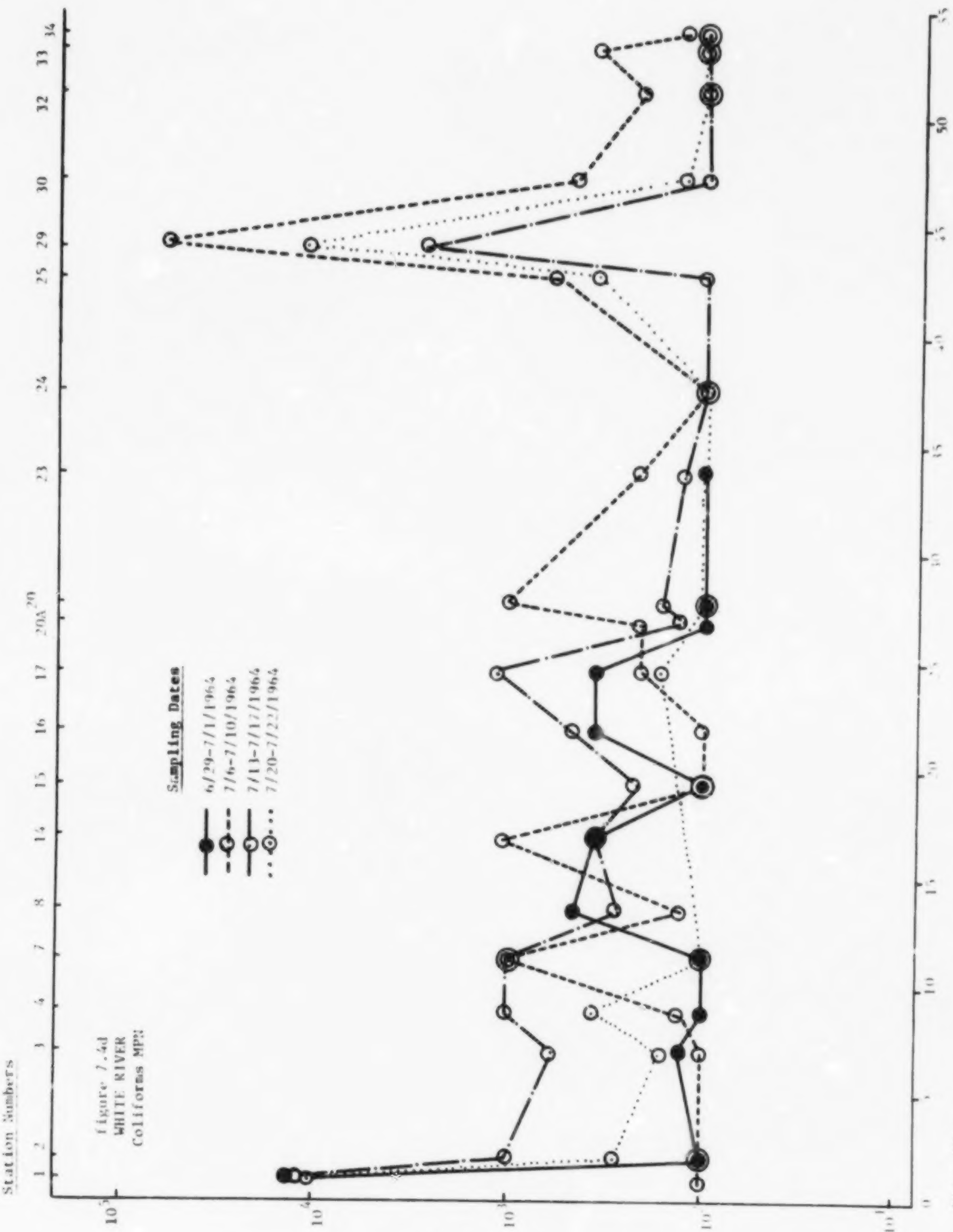


Figure 7.4d
WHITE RIVER
Coliforms MPN

Table 7.4-1

Data on Three Branches of the White River

SAMPLE STATION	RIVER MILES ABOVE INTERSECTION WITH WHITE RIVER	DATE SAMPLED	PARAMETERS MEASURED			
			DISSOLVED OXYGEN mg/1	BOD mg/1	TEMP. °C	COLIFORMS MPN
First Branch 1-1	.5	6/29 - 7/1/64	9.15	.9	24.0	1,000
		7/6 - 10/64	9.60	1.0	21.0	4,000
		7/13 - 17/64	8.95	5.7	20.0	43,000
		7/20 - 22/64				
Second Branch 2-1	1.0	6/29 - 7/1/64	8.60	.7	23.0	200
		7/6 - 10/64	8.95	.95	21.0	900
		7/13 - 17/64	9.40	.6	22.0	800
		7/20 - 22/64				
Third Branch 3-1	.5	6/29 - 7/1/64	8.75	.75	21.0	17,000
		7/6 - 10/64	7.60	1.95	23.4	19,000
		7/13 - 17/64	8.80	1.3	20.8	16,000
		7/20 - 22/64	9.50	0.75	21.2	

water in the lower reaches of the river. The temperature profile exhibits a rising trend as one proceeds from the headwaters to the confluence.

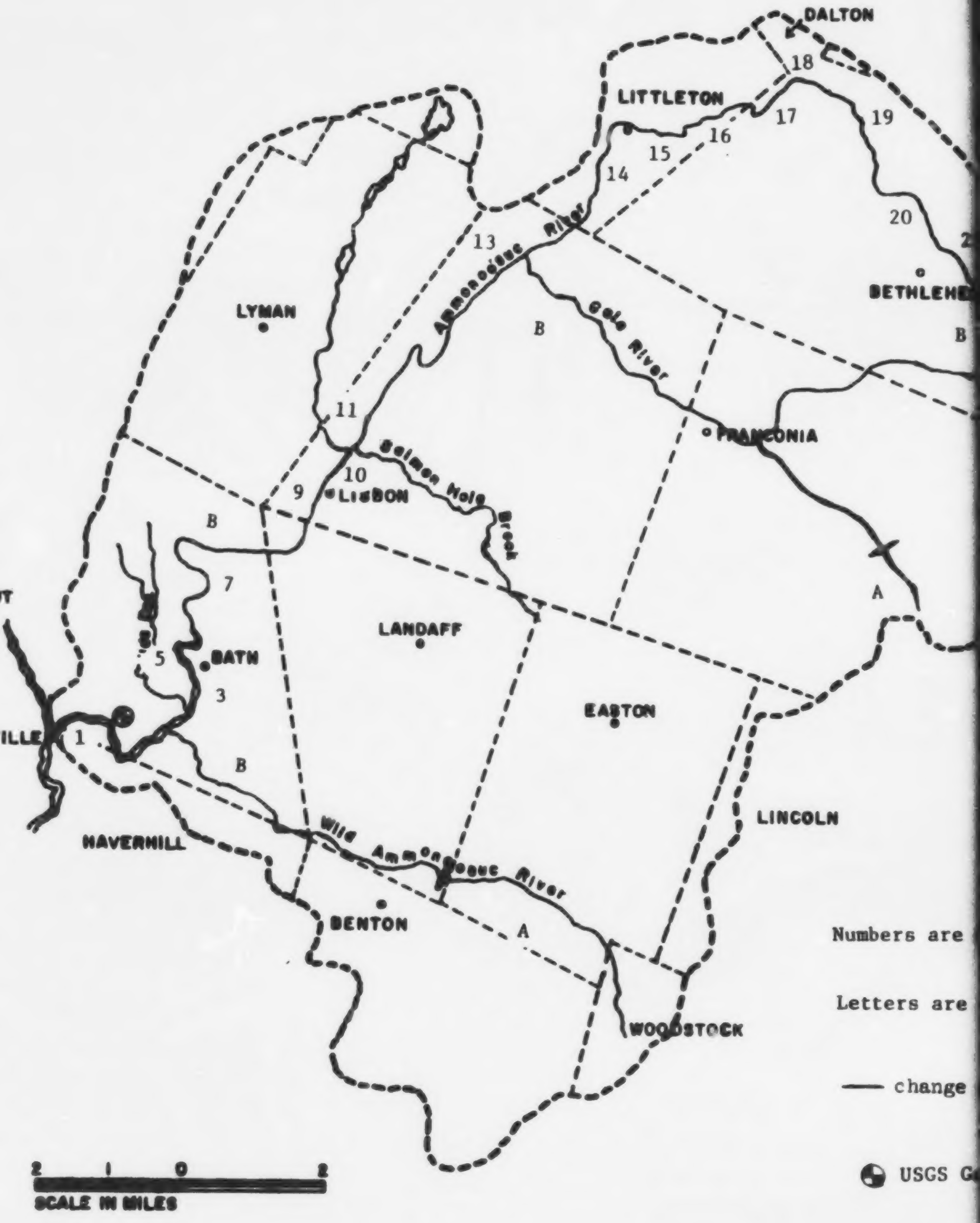
The coliform profile shows sporadic fluctuations which coincide in most cases with town locations and hence town discharges. Station 1 indicates the presence of municipal wastes from Hartford and White River Junction. The generally high concentrations of coliforms shows the influence of domestic wastes from West Hartford, Sharon, South Royalton, Royalton, North Royalton, Bethel and Rochester. The sharp decrease present after Station 20 indicates the absence of any nearby upstream developments. The effects of discharges from Rochester are felt through Station 29. The effects of the wood wastes and other discharges from Granville are experienced at Station 33. Other than the local peak at Station 33, the coliform trend seems to decline above the Town of Rochester.

Table 7.4-1 indicates the data gathered for the three branches of the White River. The high number of coliforms reported on the First, Second and Third Branches were due to discharges from the Towns of Chelsea and Tunbridge, East Randolph and Randolph, and Bethel, respectively.

At the present time, most of the sample stations record concentrations greater than 1000/100 ml and, hence, fail to meet even C-coliform standards. This is due to the general absence of treatment plants on the White River System, with the exception of the Town of Randolph on the Third Branch, which limits its treatment to primary and chlorination. However, there are treatment plants presently proposed and under construction. With the installation of these plants and the commitment to the 1977 treatment deadlines, these coliform counts should decline.

7.5 The Ammonoosuc River Basin

The Ammonoosuc River rises in the Lake of the Clouds on the western slope of Mount Washington in Sargents Purchase, New Hampshire, and flows in a westerly direction for about 21 miles to Bethlehem Junction, then northwesterly and westerly 13 miles to Littleton, and then southwesterly 22 miles, through Lisbon and Bath, to its confluence with the Connecticut River at Woodsville, New Hampshire. It has a drainage area of 402 square miles, all in New Hampshire, and a total fall of 4,560 feet in its length of 56 miles. Two important tributaries of the Ammonoosuc River are the Gale and the Wild Ammonoosuc Rivers. The Gale River is formed by the confluence of the North and South Branches of the Gale River in the Town of Bethlehem and flows in a general westerly direction 13 miles to


DALTON
18
LITTLETON
17
19
16
15
14
13
20
BETHLEHE
LYMAN
B
B
Ammonoosuc River
Gale River
11
FRANCONIA
Salmon Hole Brook
10
9
LISBON
B
7
A
CONNECTICUT RIVER
LANDAFF
5
BATH
3
EASTON
WOODSVILLE
1
B
LINCOLN
HAVERHILL
Wild Ammonoosuc River
BENTON
A
WOODSTOCK
2 1 0 2
SCALE IN MILES

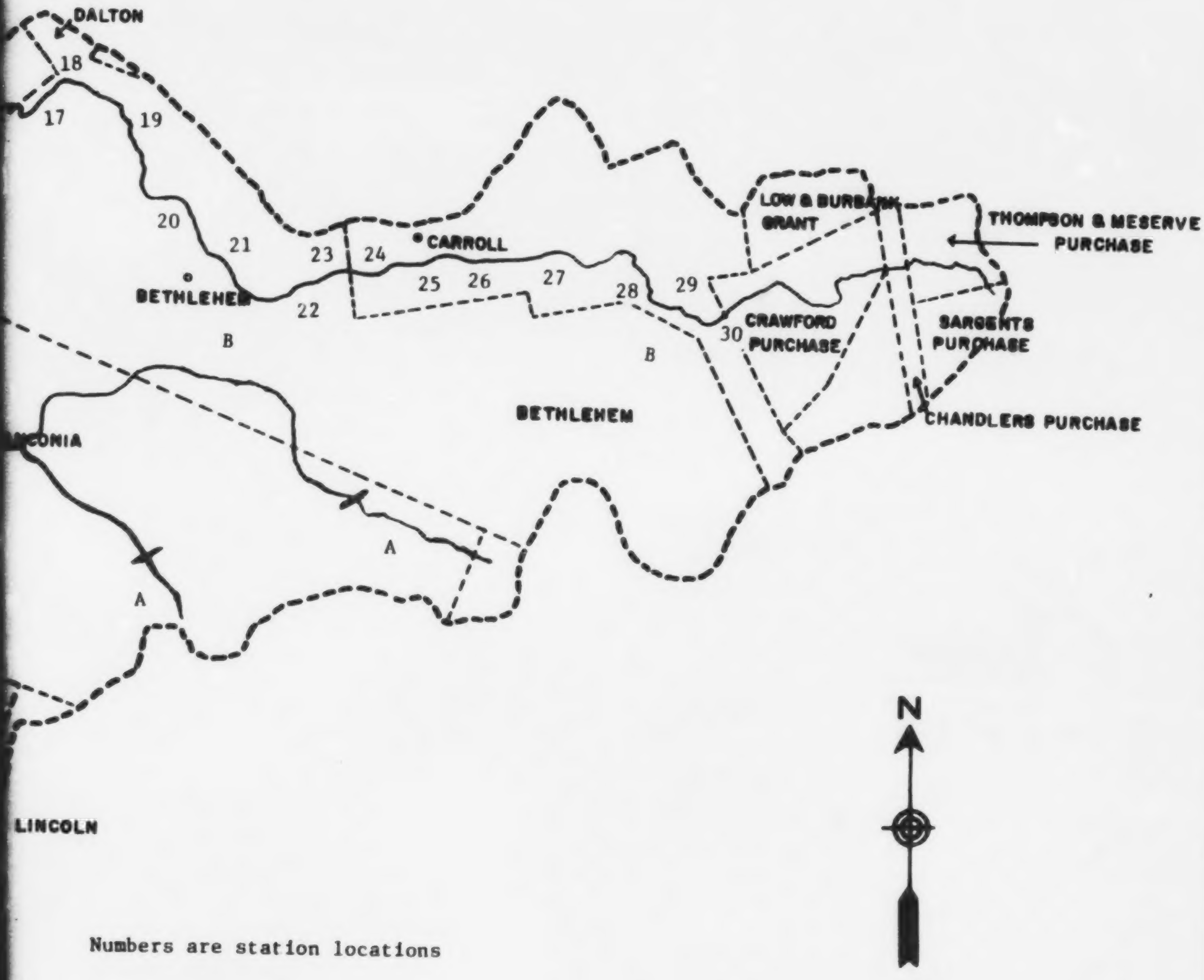
Numbers are

Letters are

— change

🌑 USGS G

A


DALTON
18
17
19
20
21
23
24
CARROLL
25
26
27
28
29
LOW & BURBANK GRANT
THOMPSON & MESERVE PURCHASE
BETHLEHEM
22
B
30
CRAWFORD PURCHASE
SARGENTS PURCHASE
B
BETHLEHEM
CHANDLERS PURCHASE
CONIA
A
A
LINCOLN
N

Numbers are station locations

Letters are use classes

— change classification

● USGS Gauging Station

B

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY

Ammonoosuc River Basin
Map 7.5

join the Ammonoosuc River at Barrett. This tributary has a drainage area of 91 square miles and a total fall of about 653 feet. The Wild Ammonoosuc River originates at Beaver Pond in Woodstock and flows northwesterly about 15 miles to its mouth at the Ammonoosuc River at Bath. It has a drainage area of 58 square miles and a total fall of 1,380 feet.

The State of New Hampshire has classified the Ammonoosuc River as class B with some upper portions of its tributaries being class A. Map 7.5 illustrates the classifications adopted and also, indicates the state sampling locations which were used for the water quality reconnaissance.

Due to the lack of any recent surveys done on the Ammonoosuc, the data used for the reconnaissance had to be compiled from the data taken on the river in 1966. Graphs 7.5 (a-d) indicate what data was available for the survey. On the whole, the information was limited to only a few parameters and it is recognized that a more updated sampling program with more consideration being given to other parameters would definitely enhance a water quality sketch of the basin.

Four principle parameters were analyzed; dissolved oxygen, temperature, pH, and coliforms. The lowest dissolved oxygen concentration observed was 6.4 which resulted in 70% saturation reading at Station 3. This was the lowest value recorded and the dissolved oxygen concentration violated the class B standards. Accordingly, the saturation limit is not to be less than 75%. Saturation levels between 70% and 75% were recorded occasionally at Stations 1 and 5, also.

The general decline in temperature recorded as one travels up the Ammonoosuc, indicates the transition from a larger river to a mountain stream. The lower temperature in the headwaters is indicative of the higher elevations and the lower ambient air temperatures where the river originates.

The pH displays a peculiar peak around 15 to 25 miles above the Connecticut River confluence. However, this peak is a result of old data and the condition no longer exists. The effects of the now abandoned portion of the Littleton Treatment Plant are recorded in this peak. Prior to 1968, the Littleton Treatment Plan handled separately the tanning wastes from a local plant. The treatment requires raising the pH to neutralize the acidic effluent usually associated with tanning wastes. Since the time of sampling, the tanning process has ceased and that part of the plant has been abandoned. The plant now releases only domestic wastes at a pH around 7.1. The pH of the river is now within the normal range.

Preceding page blank

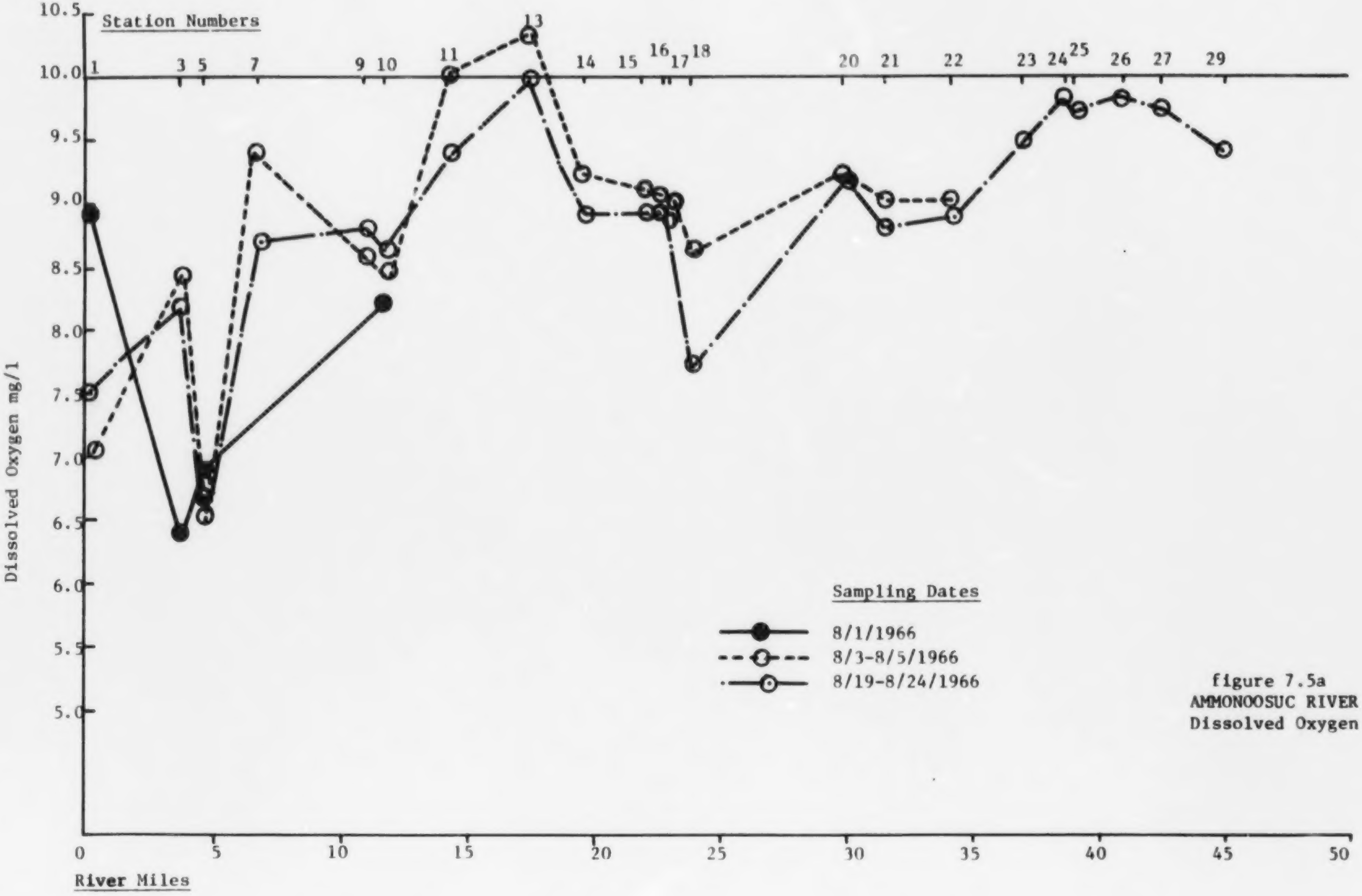


figure 7.5a
AMMONOOSUC RIVER
Dissolved Oxygen

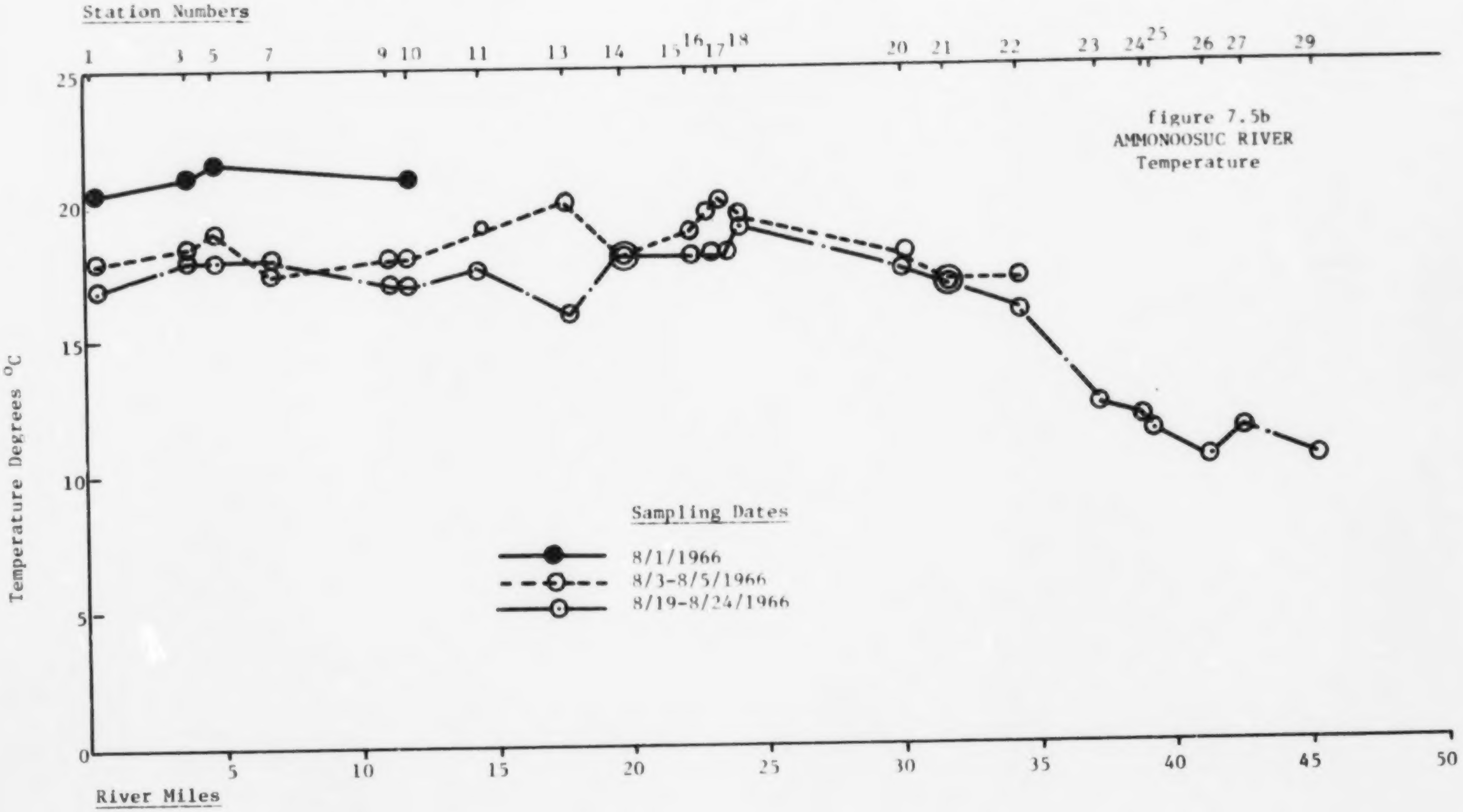


figure 7.5b
AMMONOOSUC RIVER
Temperature

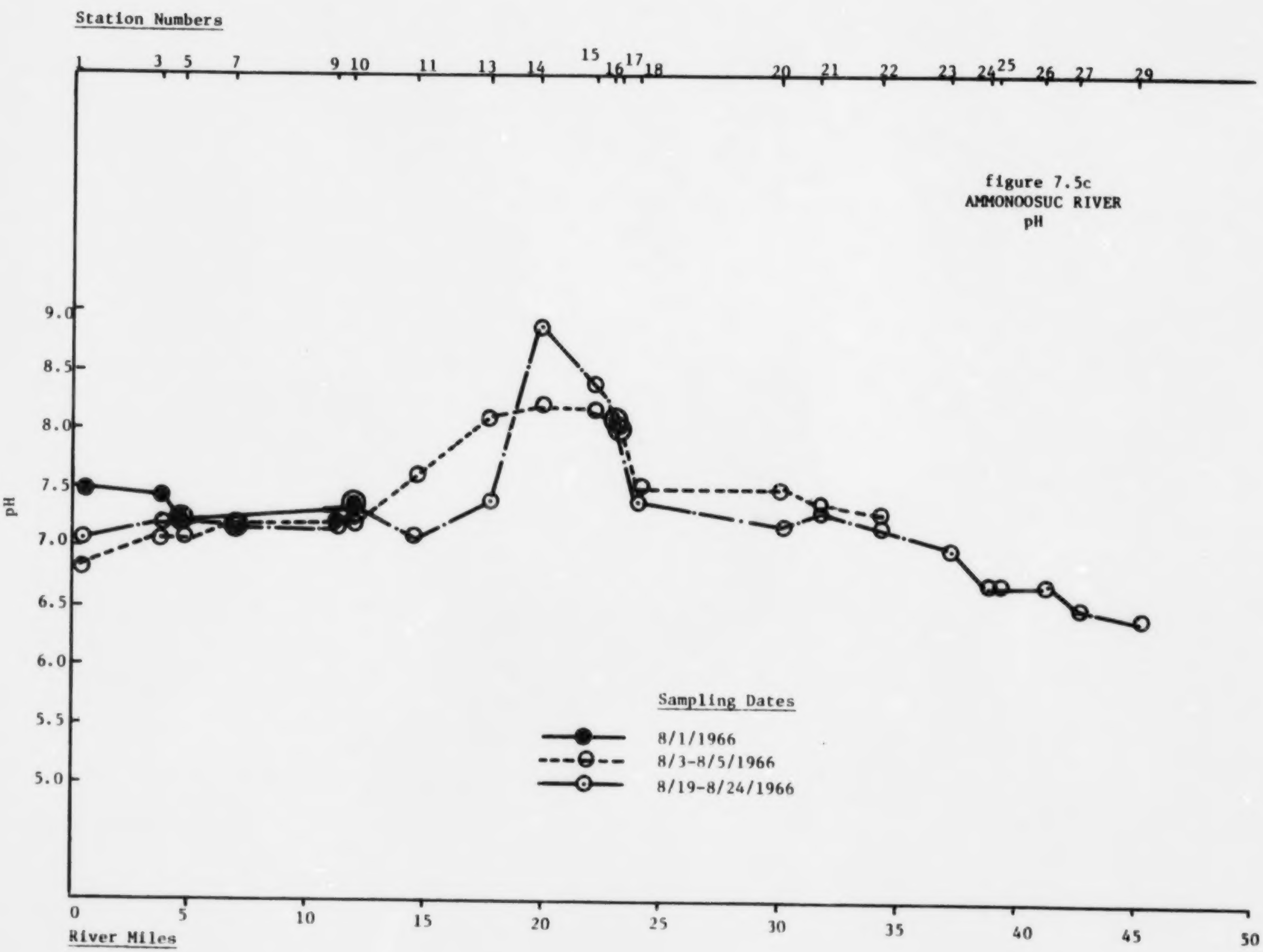


figure 7.5c
AMMONOOSUC RIVER
pH

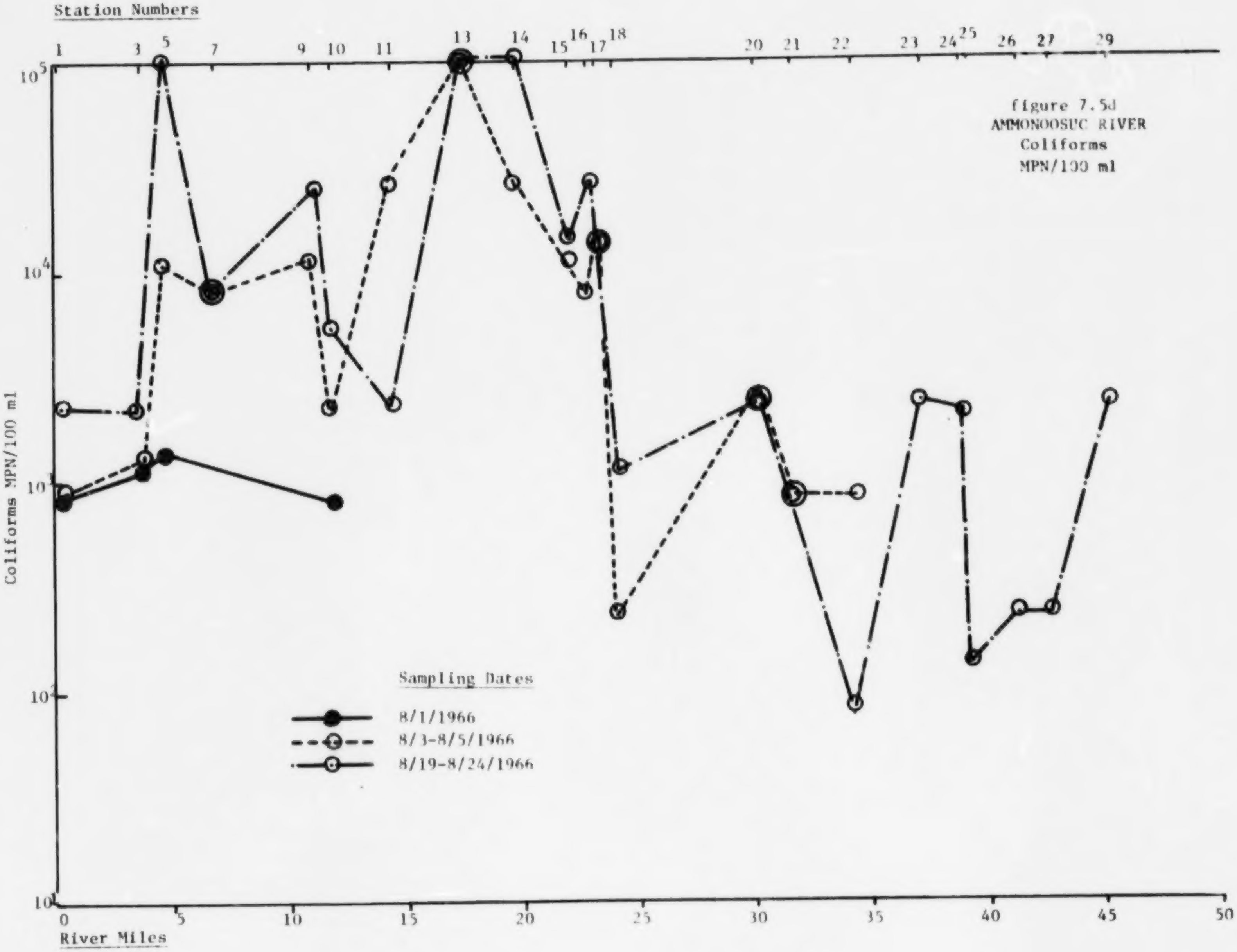


figure 7.5d
AMMONOOSUC RIVER
Coliforms
MPN/100 ml

The coliform concentrations exceed class B standards at all stations except Station 25. The high coliform concentrations are indicative of the lack of treatment at Bethlehem, Lisbon, etc. With the exception of Littleton, which has only primary treatment, there is no other significant treatment of wastes in this area. However, with the new amendments and guidelines, there are treatment plants designed and being constructed in some of these other towns.

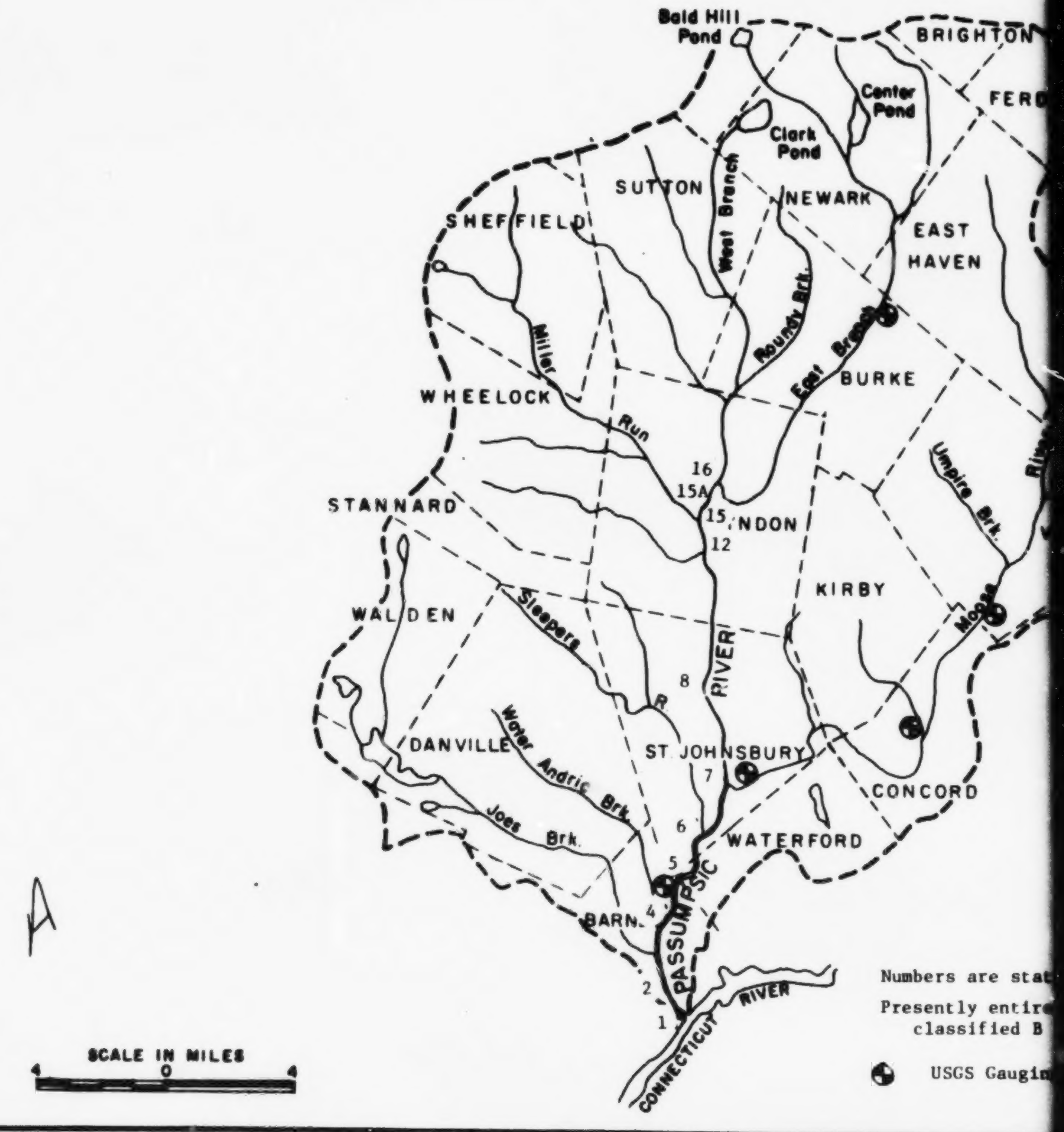
It is noted that the higher coliform concentrations recorded upstream are attributed to a local resort hotel which has a subsurface disposal system that leaches into the river.

7.6 The Passumpsic River Basin

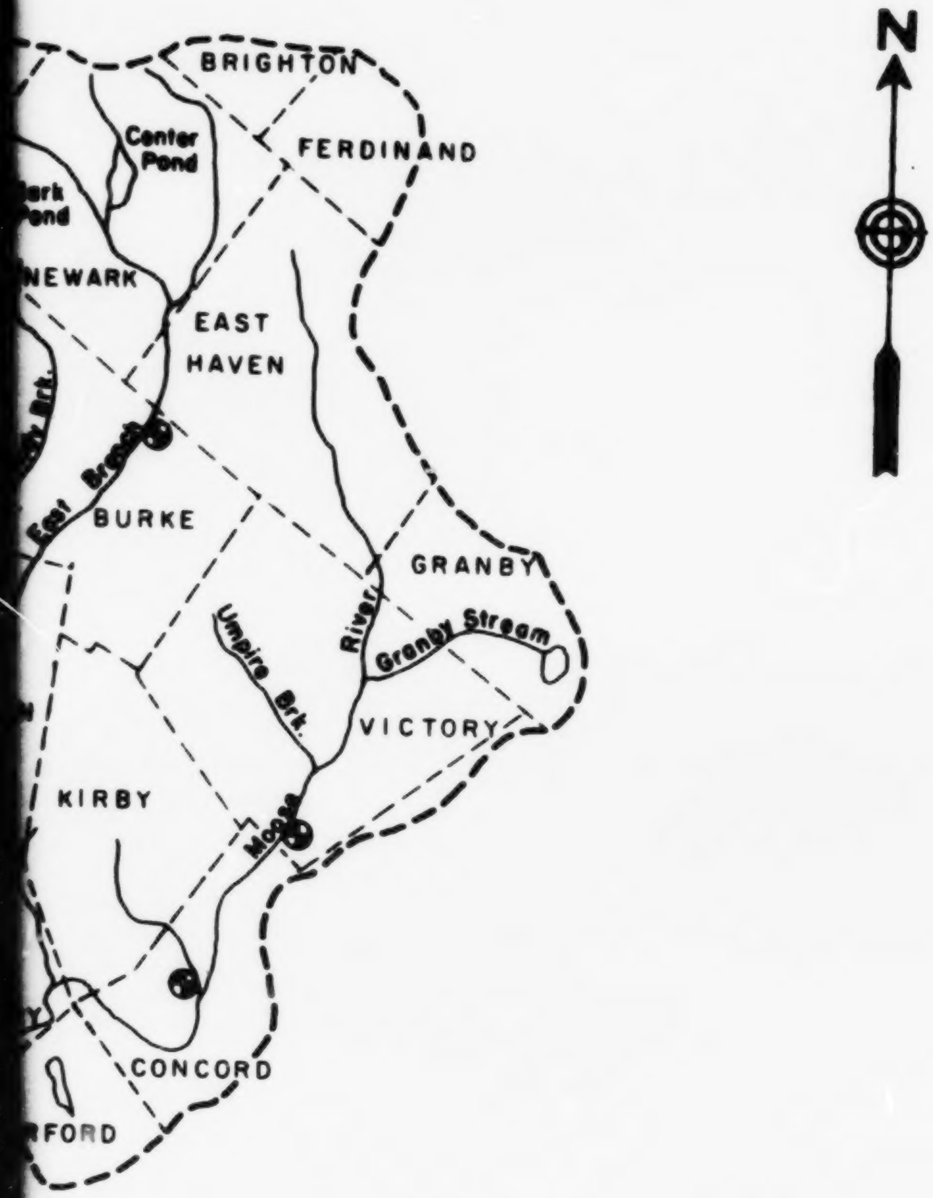
The Passumpsic River is formed by the confluence of its east and west branches in the Town of Lyndon, Vermont, and flows in a southwesterly direction to Lyndonville. From this point, it follows a southerly course through St. Johnsbury and Passumpsic to its confluence with the Connecticut River at East Barnet. The mainstem has a total length of approximately 23 miles, a total fall of about 230 feet, and a drainage area of 507 square miles, all in Vermont. The Moose River, the Passumpsic's main tributary, rises in the Town of East Haven and flows in a southerly direction to Concord and then westerly to its confluence with the Passumpsic River at St. Johnsbury, Vermont, a total distance of about 25 miles. It drains an area of 127 square miles and has a total fall of about 1230 feet, of which 770 feet are in its upper 14 miles. The West Branch of the Passumpsic drains an additional 66 square miles and adds an additional 16 miles in length, while the East Branch drains an additional 80 square miles and adds an additional 18 miles in length. The West Branch falls about 1500 feet and the East Branch falls about 1400 feet.

Map 7.6 indicates the sampling points established by Vermont and used to develop a water quality reconnaissance of the Passumpsic River Basin. As of July 1, 1971, all waters of the Passumpsic River were classified B. However, under the new standards revisions, any water immediately below a treatment plant will be reclassified C for a sufficient length to provide a bacterial safety zone for public health.

Graphs 7.6(a-g) illustrate the trends exhibited in several water quality parameters as one travels up the mainstem. The information regarding the parameters was synthesized from the data taken on the Passumpsic during 1961.


Bald Hill Pond
BRIGHTON
FERD
Center Pond
Clark Pond
SUTTON
NEWARK
SHEFFIELD
West Branch
EAST HAVEN
Roundy Brk.
East Branch
Miller
BURKE
WHEELOCK
Run
Umpire Brk.
River
16
15A
STANNARD
15
NDON
12
KIRBY
WALDEN
Sleepers
Moose
RIVER
8
R.
DANVILLE
Water Andric Brk.
ST JOHNSBURY
7
CONCORD
Joes Brk.
6
WATERFORD
5
BARN.
4
PASSUMPSIC
2
1
CONNECTICUT RIVER
SCALE IN MILES
4
0
4
Numbers are stat
Presently entire
classified B
USGS Gaugin

A


N
BRIGHTON
FERDINAND
Center Pond
ark
ond
NEWARK
EAST
HAVEN
Brk.
East Branch
BURKE
GRANBY
Granby Stream
River
Umpire Brk.
VICTORY
KIRBY
Moose
CONCORD
RFORD

B

Numbers are station locations

Presently entire Basin
classified B

● USGS Gauging Station

CONNECTICUT RIVER BASIN
SUPPLEMENTAL STUDY

Passumpsic River Basin
Map 7.6

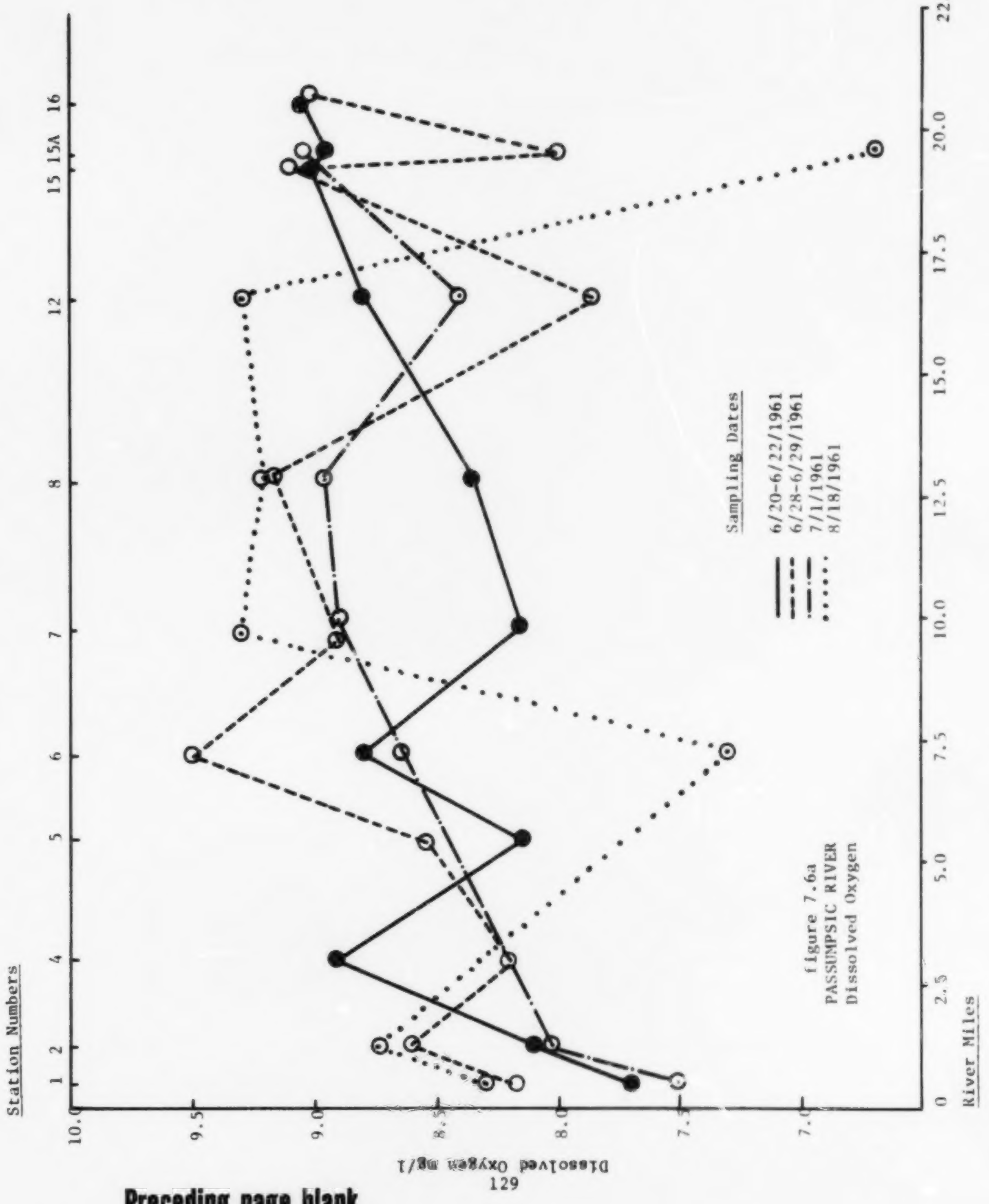


figure 7.6a
PASSUMPSIC RIVER
Dissolved Oxygen

Preceding page blank

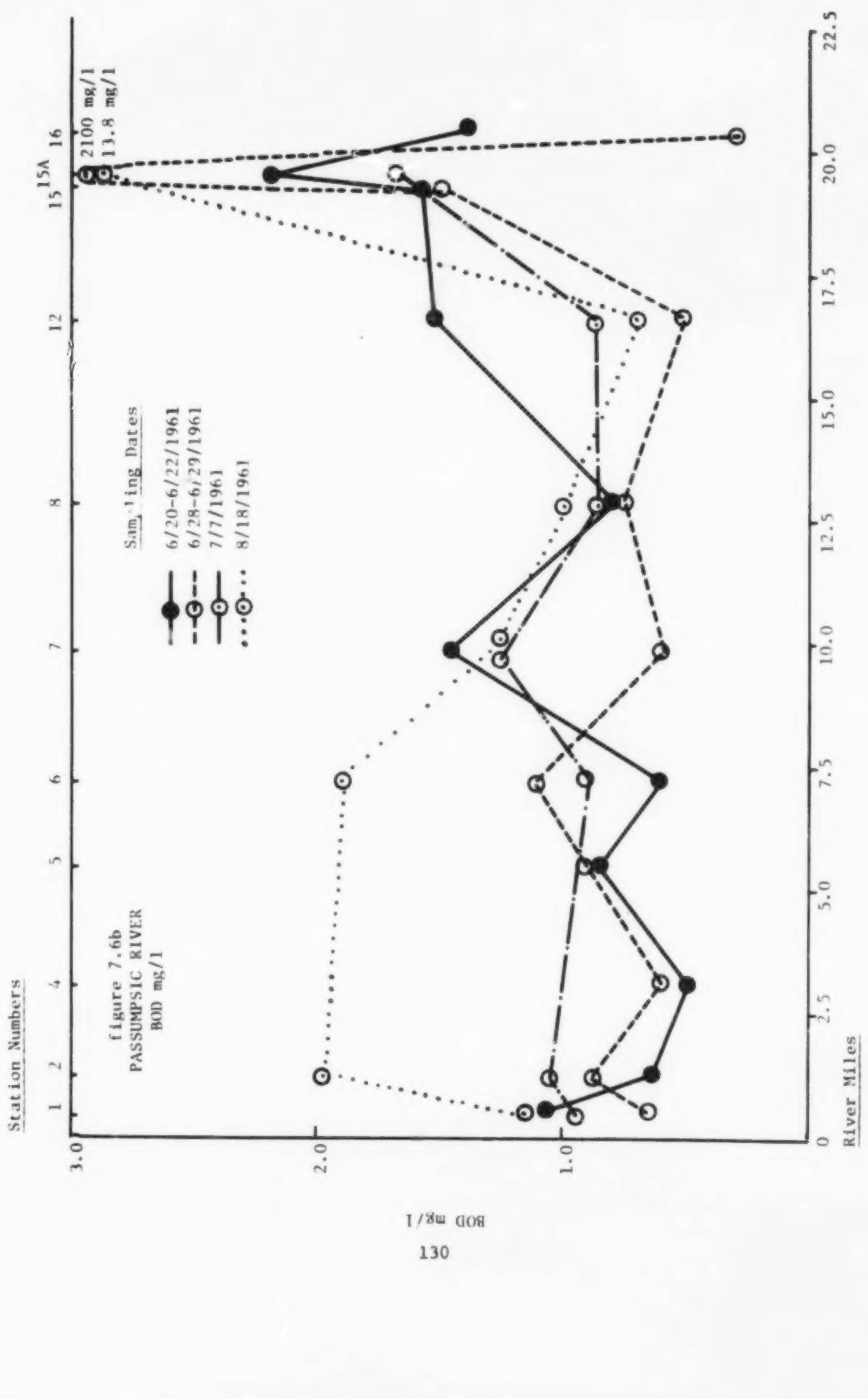


figure 7.6b
PASSUMPSIC RIVER
BOD mg/l

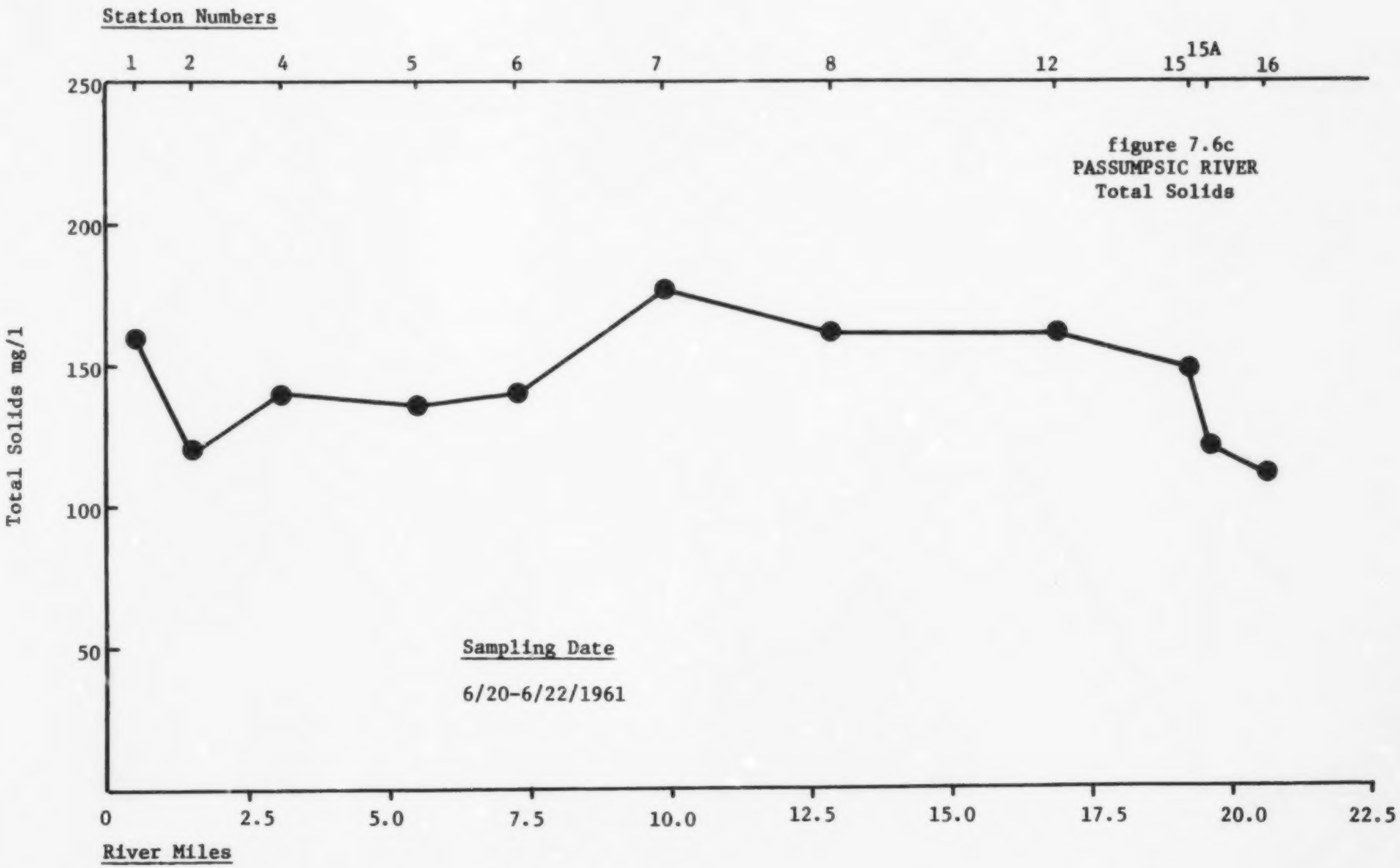
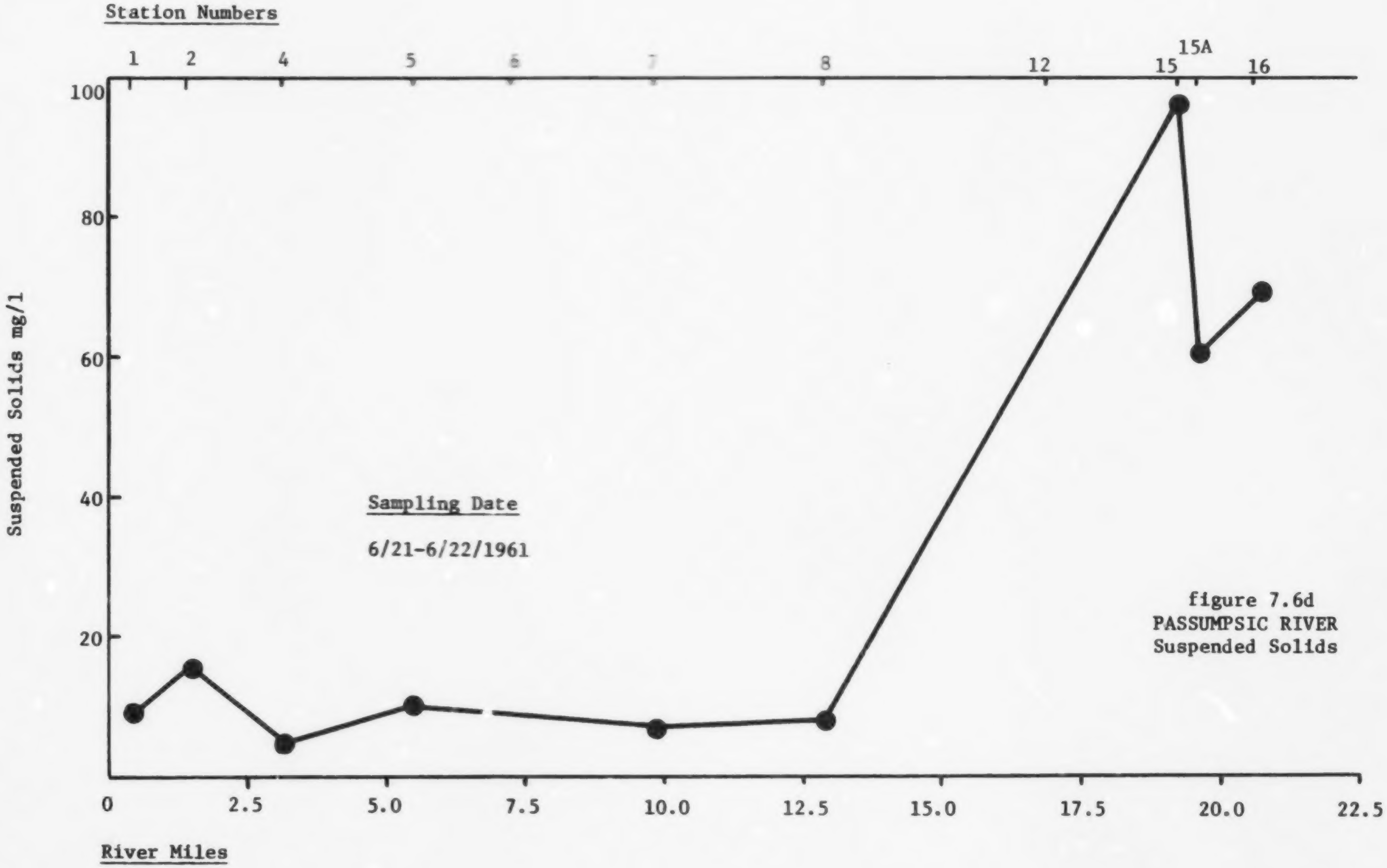


figure 7.6c
PASSUMPSIC RIVER
Total Solids

Sampling Date

6/20-6/22/1961



Sampling Date

6/21-6/22/1961

figure 7.6d
PASSUMPSIC RIVER
Suspended Solids

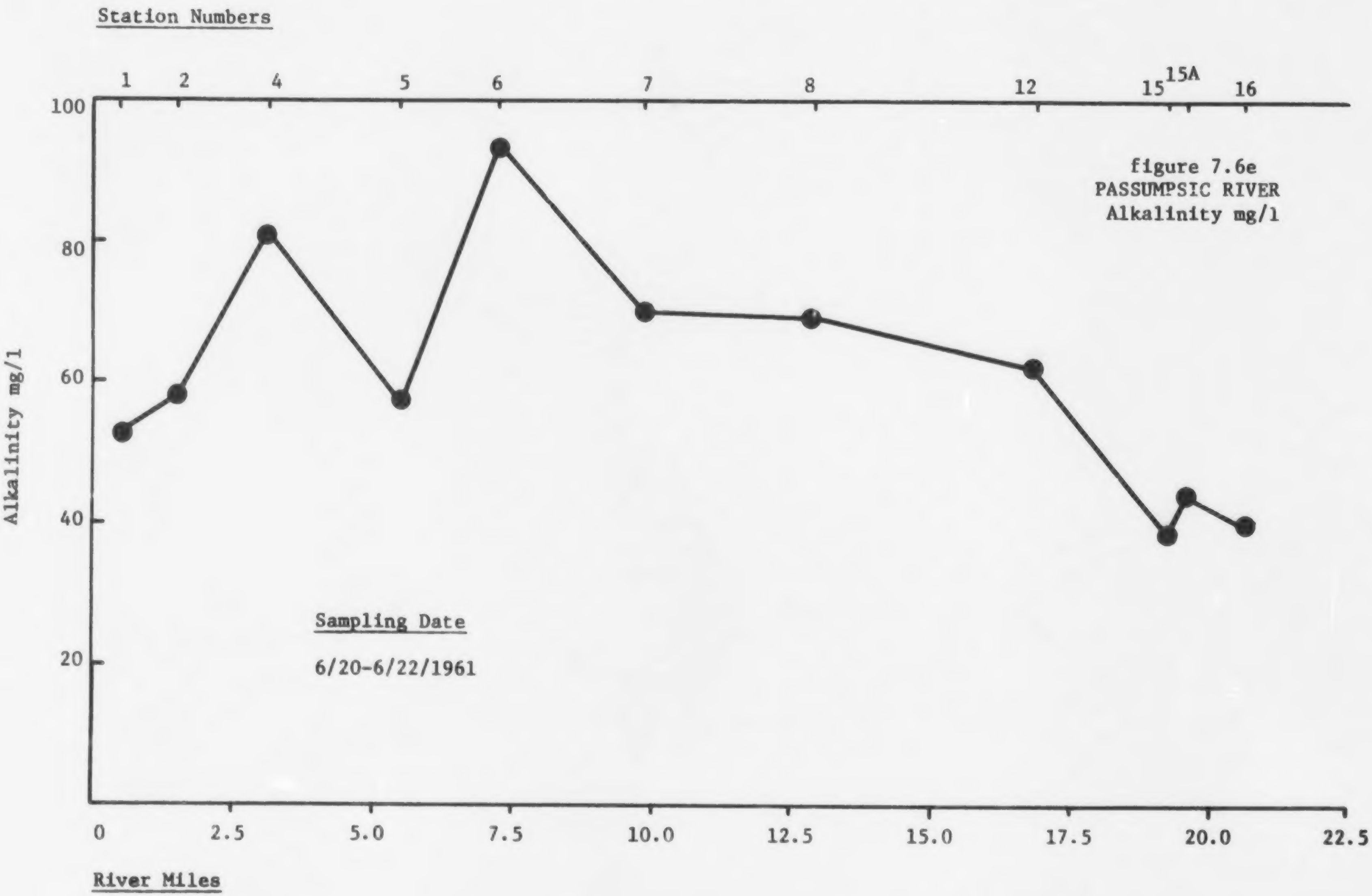


figure 7.6e
PASSUMPSIC RIVER
Alkalinity mg/1

Sampling Date

6/20-6/22/1961

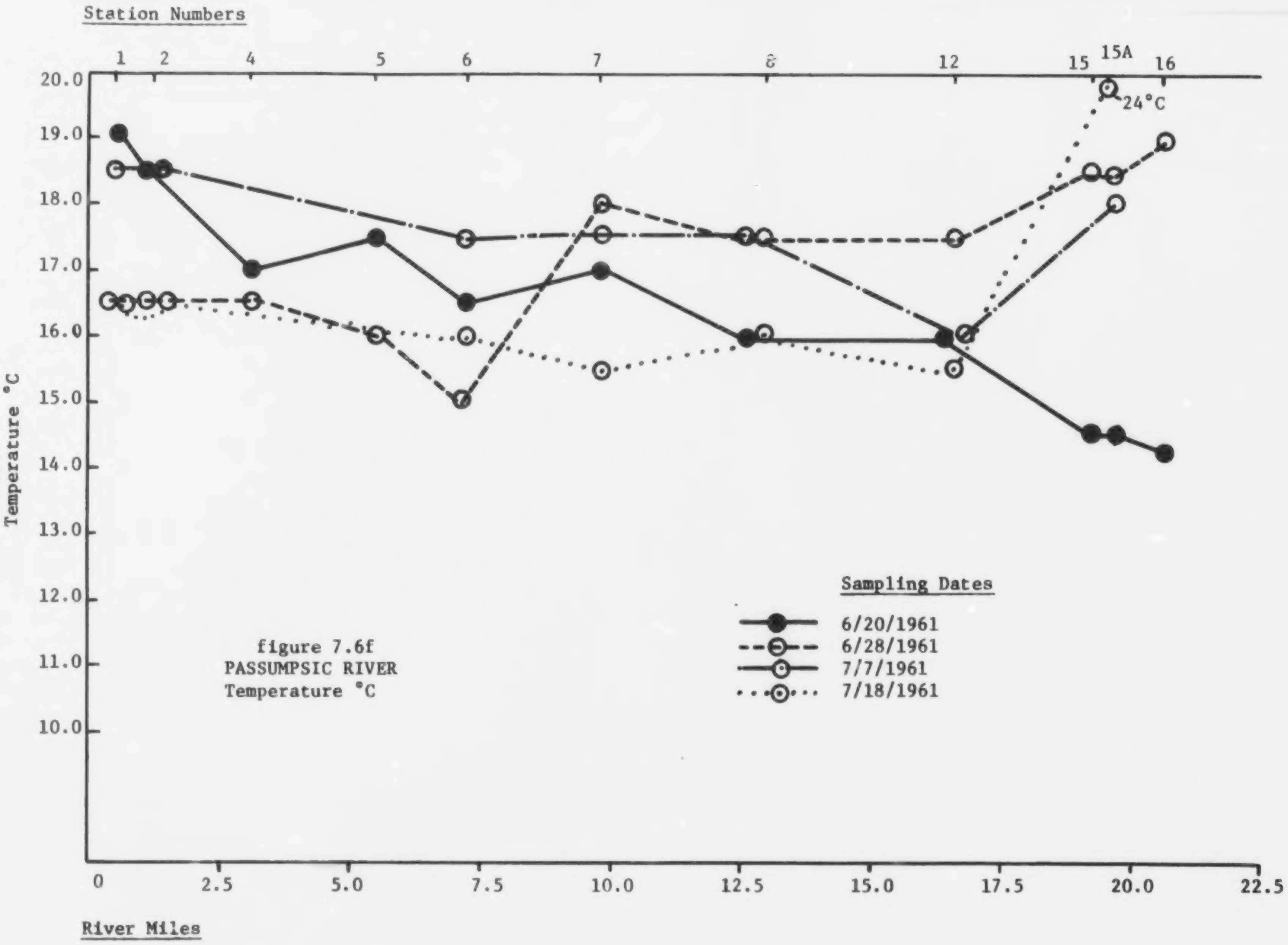


figure 7.6f
PASSUMPSIC RIVER
Temperature °C

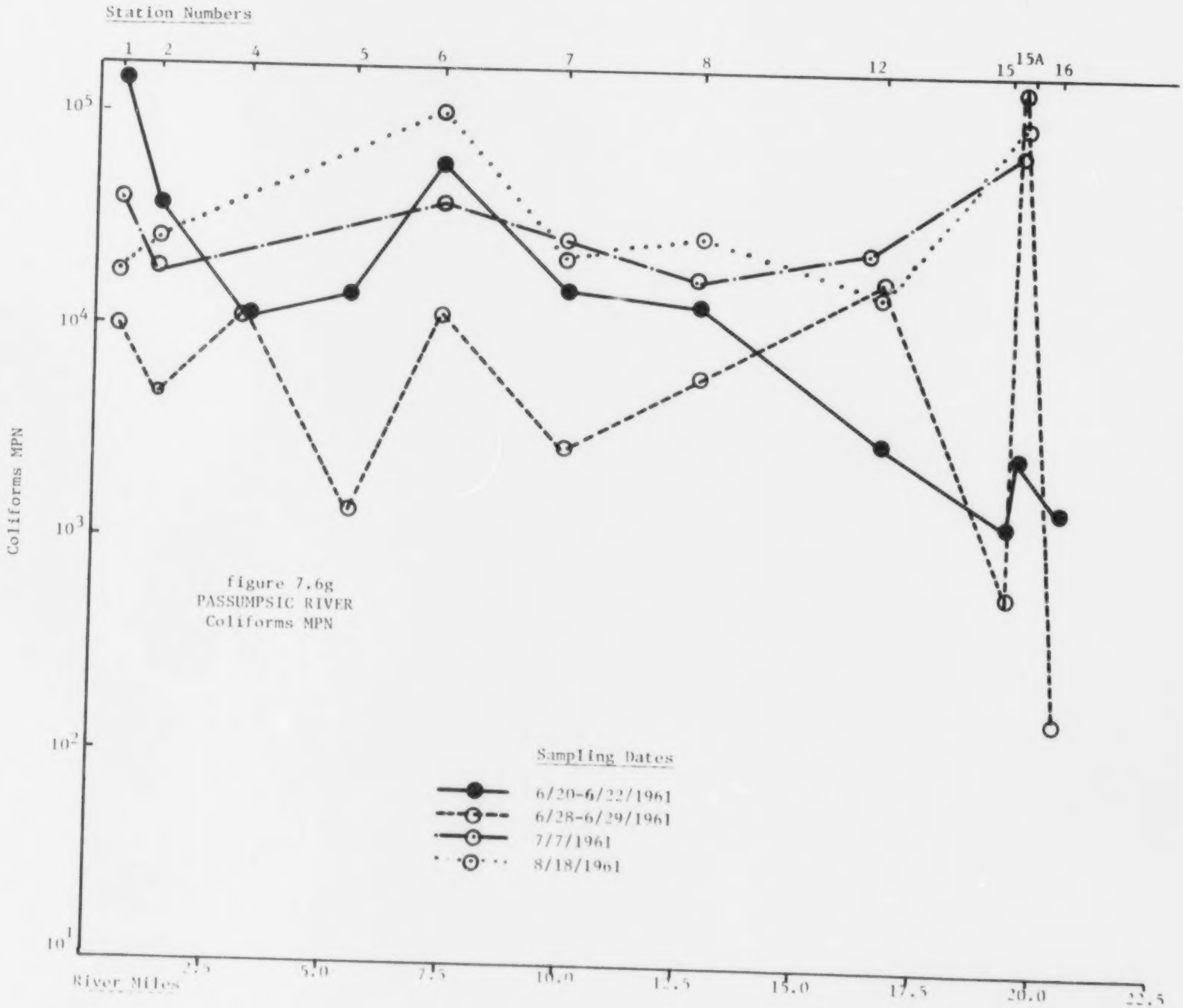


figure 7.6g
PASSUMPSIC RIVER
Coliforms MPN

The dissolved oxygen at all points measured on the mainstem was above 7.0 except at Station 15a where a value of 6.7 ppm was recorded. 7.0 complies with the specifications established for Type I water which sustains natural populations of brook trout, salmon, rainbow trout and brown trout. The two significant depressions in the DO curve between Stations 5 and 6 and at 15a show the effects of discharges from St. Johnsbury and Lyndonville. Sample 15a, for example, was taken at a sewer outfall from the Lyndonville Cooperative Creamery (subsequently closed).

The BOD curve illustrates more graphically, the effects of discharges from St. Johnsbury, the Sleepers River and Lyndonville. Station 6 located just below St. Johnsbury shows a rise in the BOD. The BOD is generally assimilated by the stream and remains low, however. Stations 15 and 15a show the high BOD load discharged to the Passumpsic at Lyndonville. It is not until Station 12, about 2.5 miles downstream and above Lyndon, that the BOD load from Lyndonville is effectively assimilated. This is indicated by the lower BOD concentration values at Stations 7, 8, 12 and 16.

Total solids concentration remains relatively constant but the suspended solids shows a sharp rise again at Station 15.

The alkalinity peak at Station 6 shows the influence of the Sleepers River. The alkalinity recorded in the Sleepers River was relatively high. This might be a consequence of the previous discharges along the river. Since this data was recorded, the sanitary discharges on the Sleepers River have been eliminated. The alkalinity concentrations seem to rise slightly, as the river passes through the more developed areas.

The temperature profile is generally constant as the river flows to the lower elevations away from the headwaters. The one anomaly occurs around Station 15a. This is probably due to elevated temperatures of wash of other wastewaters discharged from the creamery.

The coliform MPN shows several peaks. These peaks occur at the stations around Lyndonville and below St. Johnsbury. The Sleepers River also contributes coliforms to Station 6 and below. The only treatment plant previously in operation was located at St. Johnsbury. This plant was destroyed by the summer floods in 1973. However, with the elimination of most sanitary discharges on the Sleepers River, with the installation of treatment plants already planned, and with the closing of the creamery, these concentrations will decline. In no case during the sampling period did these stations meet the presently established B standards for coliforms (and possibly not even C standards), but compliance with the 1972 Amendments should be responsible for the elimination of this situation.

GLOSSARY

Buffering capacity - a measure of a solution's resistance to changes in pH values when acids or bases are added to or formed within the solution. The resistance is provided by substances in the solution called buffers.

Correlation coefficient - the co-variance of 2 parameters divided by the square root of the product of the 2 parameters' variances.

Epilimnion - the upper layer of warm water in a thermally stratified lake, containing more oxygen than the lower layers.

Euphotic zone - the upper most portion of a body of water into which light enters to a degree sufficient for photosynthesis and the consequent growth of plants.

Eutrophication - "nutrient enrichment" - a natural aging process which involves an increase in the biologic productivity of a body of water as a result of nurtient enrichment from natural sources. Man's influence has accelerated the process by allowing excessive amounts of nutrients to enter an aquatic ecosystem. This is known as "cultural eutrophication."

Heterotrophic activity - the activity of organisms who obtain food from organic material only. These organisms are unable to use inorganic matter to form proteins and carbohydrates.

Hypolimnion - the lower-most non-circulating layer of cold water in a thermally stratified lake, usually deficient in oxygen.

Pedology - the scientific study of soils.

Regression coefficient - the slope of the regression line.

Thermocline - a layer of water between the warmer, surface zone and the colder, deep-water zone in a thermally stratified body of water, in which the temperature decreases rapidly with depth, usually at least 1°C with each meter of increased depth. Also referred to as the metalimnion.

Trophogenic - of or relating to or being the upper level of a lake in which inorganic matter is converted to organic matter through photosynthetic activity.

Tropholytic - of or relating to or being the deeper part of a lake in which dissimilation of organic matter tends to predominate.

Preface to **Appendix A,B.**

Discussion of Flow Regressions Performed for Connecticut River Supplemental Study

These water quality analyses were undertaken as part of the broader Connecticut River Supplemental Study. In particular, consideration was given to the available water quality data at 3 monitoring stations along the Connecticut (namely Wilder, Northfield and Enfield), with the primary purpose being to determine whether there is any relationship between flow and various water quality parameters, and to characterize such relationships that may exist.

With this goal in mind, it is clear that any dealings with the data must be of an exploratory nature. The investigations attempt to uncover patterns in certain parameters at particular flow levels, as well as presenting a means for comparing patterns among flow levels, among parameters, among stations, and describing any interactions between these factors.

More specifically, all available flow data along with all water quality measurements made in a given time period at these stations was compiled in two parts: one for the low flow period of July-September and the other for the high flow period of March-May. The data for each station within each flow category (i.e. high or low) was then further subcategorized by flow -- the main criteria for subdivision being that each group include sufficient data for analyses.

The object then, was to provide some means of summarizing the various relationships between each flow group and each parameter for which there was sufficient data available. For this purpose a linear regression analysis was performed in each possible case with flow being the independent variable and the various water quality indicators being the dependent variables.

The output is in the following order:

		Parameter 1	Parameter 2	Parameter 3
Enfield	High Flow	Group 1	Group 1	etc.
		" 2	" 2	
		" 3	" 3	
		" 4	" 4	
		" 5	" 5	
	Low Flow	" 6	" 6	
		" 7	" 7	
		" 8	" 8	
Northfield	High Flow	" 9	etc.	
		" 10		
		" 11		
		" 12		
	Low Flow	" 13		
		" 14		
		" 15		

The total number of analyses performed is as follows:

Enfield	5 high flow groups 3 low flow groups

Sufficient data in all 12 parameters in all 8 groups - total of 96.

Northfield	4 high flow groups 3 low flow groups

Sufficient data in all 12 parameters in all 7 groups - total of 84.

Wilder	2 high flow groups 2 low flow groups

Much missing data - thus allowing only approximately 1/2 the otherwise possible number of analyses.

It is now possible to determine which of the pairs of flow and parameter exhibit a significant linear relationship. Once this is completed, one can investigate whether the significant relationships are unique to a particular flow region, a particular station, some parameter, or some interaction of these. In addition, the type of relationship in each case is characterized by the given regression equation so that it is possible to determine whether the type of relationships are the same for any noted pattern of significant results, i.e., direct or inverse and how strong the relationship as measured by the slope (or correlation coefficient) of the fitted line.

NOTE: During analysis, the only changes made in the original data was editing (1) to prepare data for BMD* package program and (2) to reorder the data points so the regressions were printed in the desired order.

*BMD program - Biomedical Programs edited by W.J. Dixon, University of California Publications and Automatic Computations No. 2. University of California Press, Berkeley, 1971.

TABLE OF GROUP NUMBER CODES

Group	1	High flow groups (in decreasing order)	Enfield
	2		
	3		
	4		
	5		
	6	Low flow groups (decreasing flow order)	
	7		
	8		
Group	9	High flows	Northfield
	10		
	11		
	12		
	13	Low flows	
	14		
	15		
Group	16	High flows	Wilder
	17		
	18	Low flows	
	19		

NOTE: High flow and low flow groups are subcategorized by flow level, in decreasing order.

PARAMETER CODES

Parameter		
1	Temperature	°C
2	DO	mg/l
3	BOD	"
4	COD	"
5	pH	-
6	alkalinity	mg/l
7	solids	"
8	NH_3-N_2	"
9	phosphates	"
10	hardness	"
11	sulfates	"
12	chlorides	"

The analyses were also performed in lb/day (except for temperature and pH). The results as expected are somewhat different, as the transformation from concentrations to loadings induces an artificial relation with flow.

Interpretation of Computer Outputs

This discussion is intended as an aid in interpreting the submitted computer outputs.

In each case, one fits the linear regression model $Y_i = \alpha + \beta x_i + e_i$ (where the errors are assumed independently and normally distributed) and one is given the regression equation $\hat{Y} = ax+b$

Where 'b' is the estimated value of the intercept;
'a' is the estimated value of the slope or regression coefficient; and one predicts values of the parameter (Y) simply by plugging values of flow (X) into the equation.

Other summary statistics included in the computer output are the X and Y means and the correlation coefficient for X and Y.

One is interested in the significance of the linear relationship between X and Y, as measured by the correlation coefficient, or nearly equivalently the regression coefficient. In either case, one tests the hypothesis Ho: β=0 (population regression coefficient = 0. which generally indicates that population correlation coefficient = 0, which in turn indicates no linear relationship between the 2 parameters). If based on the appropriate test statistic, one can reject this hypothesis (with a low probability α that one is falsely rejecting this hypothesis - i.e. it is actually true) then there is exhibited a significant relationship. The appropriate test statistic is 'F' - compare F value of computer output with the table values for the appropriate degrees of freedom and reject hypothesis Ho if F observed is greater than F table.

Analysis and Results

The status (significance or non-significance) of the various regressions were determined in accordance with the F test just described. The results are summarized in tabular form for both clarity and visual appeal. (See Table P-I)

In particular, let
'0' represent no significant relationship - i.e. any observed correlation is attributable to random variation.
'1' represent significant direct relationship (i.e. positive slope)
'2' represent significant inverse relationship (i.e. negative slope)

The tests were computed at the .05 level of significance. That is, if the analysis were repeated 100 times, then 5 of the 100 times we would falsely claim significance. In fact, in performing approximately 200 analyses, approximately 10 claims of significance can expect to be false.

TABLE P-I

Group Parameter mg/1	Enfield								Northfield							Wilder			
	High flow					Low flow			High flow				Low flow			High flow		Low flow	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-
2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	-	-	-	-
3	0	0	0	0	0	0	2	2	1	2	0	0	0	0	0	-	-	-	-
4	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	-	-	-	-
5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-	0	-	-
6	2	0	0	0	2	2	0	0	0	0	1	2	0	0	0	0	1	0	0
7	0	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-
10	2	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

'-' represents insufficient data for analysis
'0' represents no significant relationship between flow and parameter
'1' direct relationship - positive correlation
'2' inverse relationship - negative correlation
= .05

In light of this, Table P-I indicates that one must conclude, based on the data, that there cannot be claimed any real relationships between flow and the parameters, and no real trends in any station or flow group.

It is worth pointing out that the data has been compiled from many sources and that therefore "real" relations may be obscured by poor data. Thus a correlation of say -.4 which is not significant, may well be significant if the inappropriate data points were eliminated or more data was added to the existing body of information.

On the other hand, statistical significance of a certain claim need not imply practical importance. In other words, even if the hypothesis of no relation is rejected in the light of a sample correlation of -.4, what is the implication of this event?

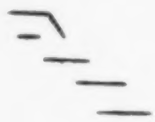
This question is best handled by considering the square of the correlation coefficient; $r^2 = .16$ in this case. r^2 is a measure of the proportion of variation in a parameter that may be explained by the parameter's relation to flow.

Clearly the statement that 16% of the variation in BOD is related to flow and 84% is related to other factors cannot be of much benefit in practice.

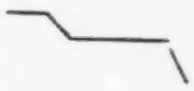
The next step in the analysis is to pool the data in the subcategories of low flow and of high flow at each station for each parameter. The purpose of this is to determine whether there is any relation that might have been obscured by lack of information in the subgroup, which might appear in the major category. For instance, if the subgroups relate in any one of the following manners, then the relationship in the total group could be significant whereas most of the subgroup relations are not.

(a) -----Group 1
-----Group 2
-----Group 3
-----Group 4
-----Group 5

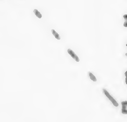
(c)



(b)



(d)



if non-significant
mild trend obtains
in several groups
then overall trend
may be significant.

i.e. in (a), (b), (c) there may be no strong relations within groups, but the trend between groups may be strong enough to produce overall linear significance.

The results of this pooled analysis appear in Table P-II. It is worth noting that a correlation of -.4 which was not significant in the subgroups is now significant, as the mass of pooled data is sufficient evidence for claiming that the trend is not attributable to random variation.

Nevertheless, the significant relations are weak, the correlations mild, and the results must be considered from a practical point of view. In other words, the significant correlations are generally between $|.3|$ and $|.5|$ (most often between -.3 and -.5) which indicates that from 10% to 25% of variation of the parameters is explained by variation in flow. At best, based on the present data one may say that under low flow and high flow, the concentrations generally have an inverse linear relationship to flow, which is most dramatic at Enfield during low flow. However, neither group at any station is of much use for predicting parameter concentrations under certain flow conditions, as the variables are never very highly correlated, and so most of the variation in the parameters must be due to other factors.

TABLE P-II Relationships Determined by Linear Regression Analysis for Concentrations

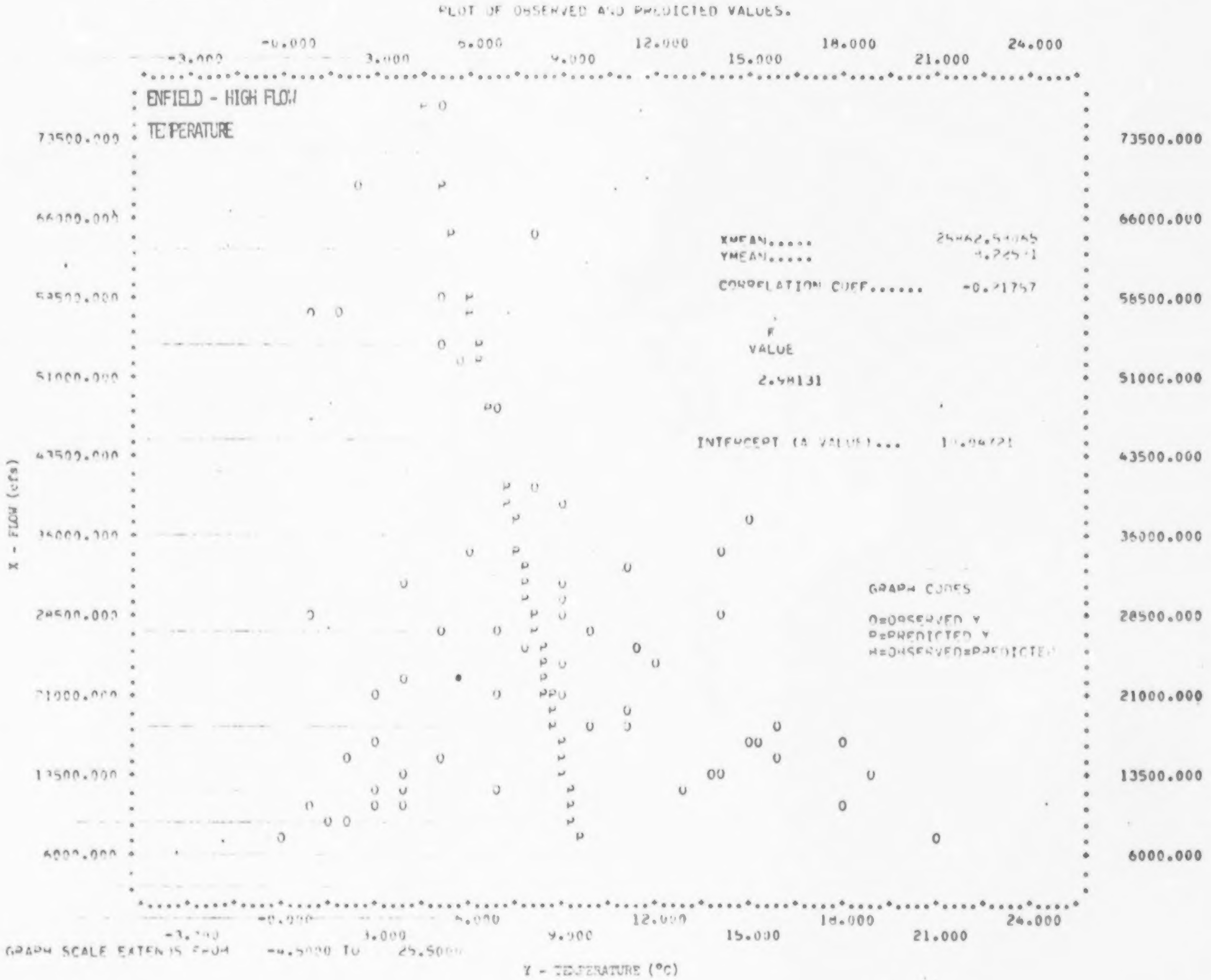
Parameter	ENFIELD		NORTHFIELD		WILDER	
	High Flow	Low Flow	High Flow	Low Flow	High Flow	Low Flow
Temperature	α =.10 2 r =-;22	0	0	0	-	-
Dissolved Oxygen	α =.01 1 r =.51	0	α =.025 1 r =.34	0	-	-
BOD	α =.025 2 r = -.32	α .01 2 r =-.57	α =.10 2 r =-.24	0	-	-
COD	0	α =.01 2 r = -.46	0	0	-	-
pH	0	0	0	0	0	-
Alkalinity	α =.01 2 r =-.74	α =.01 2 r =-,41	α =.01 2 r =-.55	α =.025 2 r =-.36	α =.10 2 r =-.30	0
Solids	0	α =.05 2 r =-.33	α =.01 2 r =-.40	0	α =.10 2 r =-.51	0
NH_3-N_2	0	α =.01 2 r =-.36	0	0	-	-
Phosphates	α =.05 2 r =-.28	α =.01 2 r =-.56	0	α =.10 1 r =.27	-	-
Hardness	α =.01 2 r =-.80	α =.01 2 r =-.54	α =.01 2 r =-.50	α =.10 2 r =-.26	0	0
Sulfates	0	α =.01 2 r =-.41	0	α =.025 1 r =.33	α =.10 2 r =-.33	α =.05 1 r =.41
Chlorides	α =.01 2 r =-.39	α =.01 2 r =-.37	α =.01 2 r =-.40	0	0	0

- - Insufficient Data
2 - Inverse Relation
1 - Direct Relation
0 - No Relation

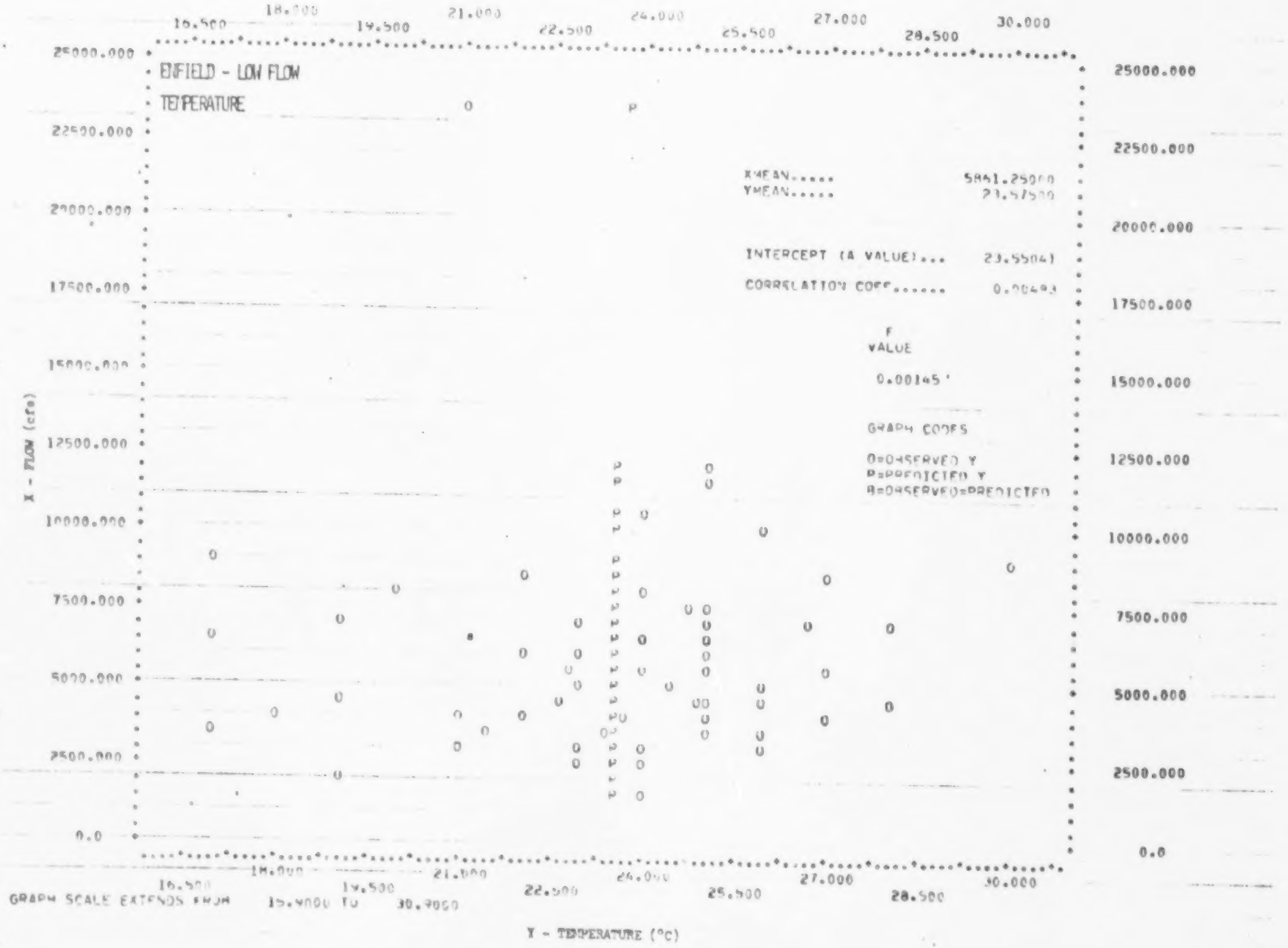
α = level of significance
r = correlation coefficient

APPENDIX A

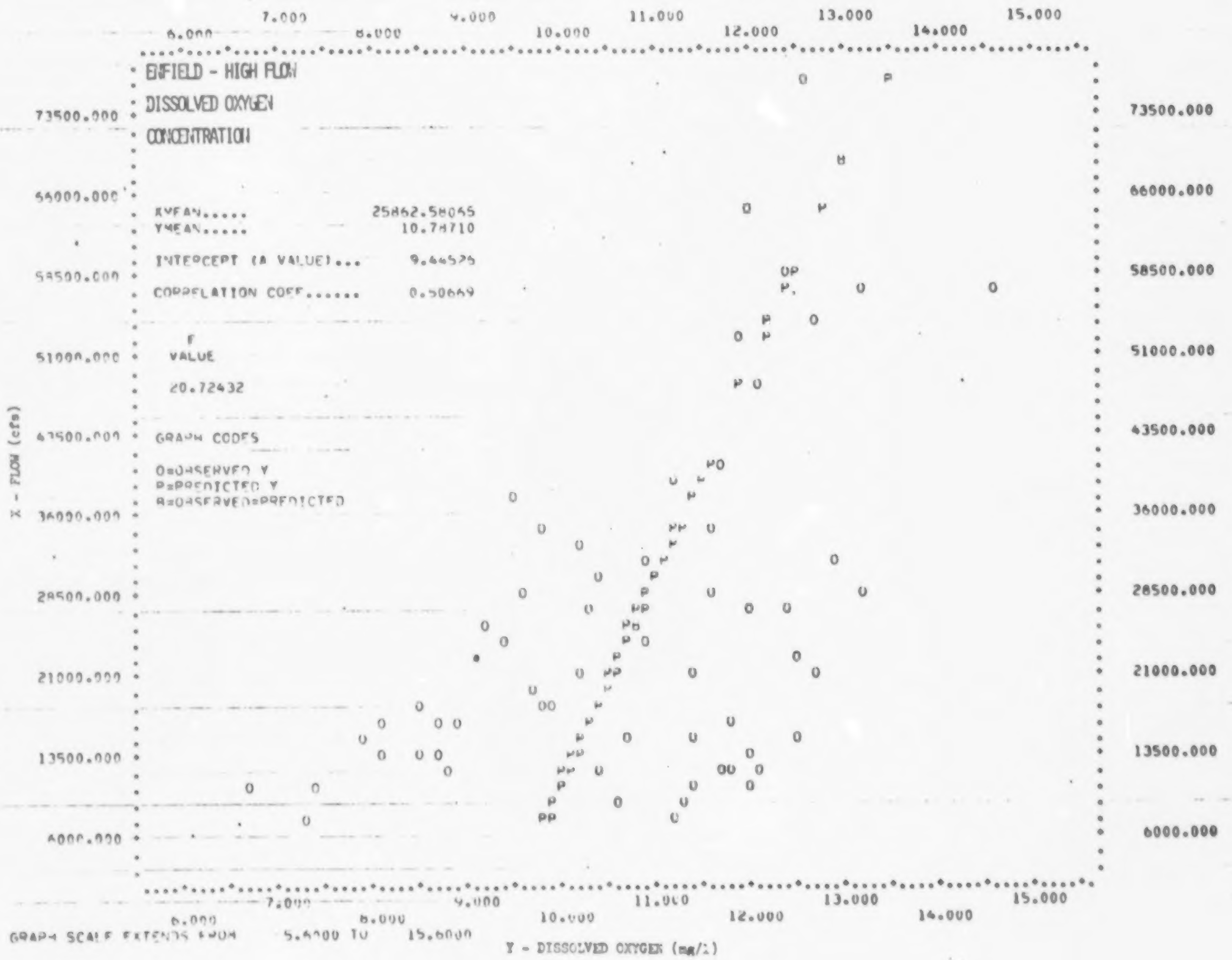
Linear Regressions Comparing
Stream Flow to Concentrations
for Various Parameters

PLOT OF OBSERVED AND PREDICTED VALUES.
ENFIELD - HIGH FLOW
TEMPERATURE
-3.000
-0.000
3.000
6.000
9.000
12.000
15.000
18.000
21.000
24.000
73500.000
66000.000
58500.000
51000.000
43500.000
36000.000
28500.000
21000.000
13500.000
6000.000
X - FLOW (cfs)
Y - TEMPERATURE (°C)
XMEAN..... 25462.54065
YMEAN..... 8.72541
CORRELATION COEF...... -0.21757
F VALUE 2.58131
INTERCEPT (A VALUE)... 10.94721
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
H=OBSERVED=PREDICTED
GRAPH SCALE EXTENDS FROM -4.5000 TO 25.5000

PLOT OF OBSERVED AND PREDICTED VALUES.



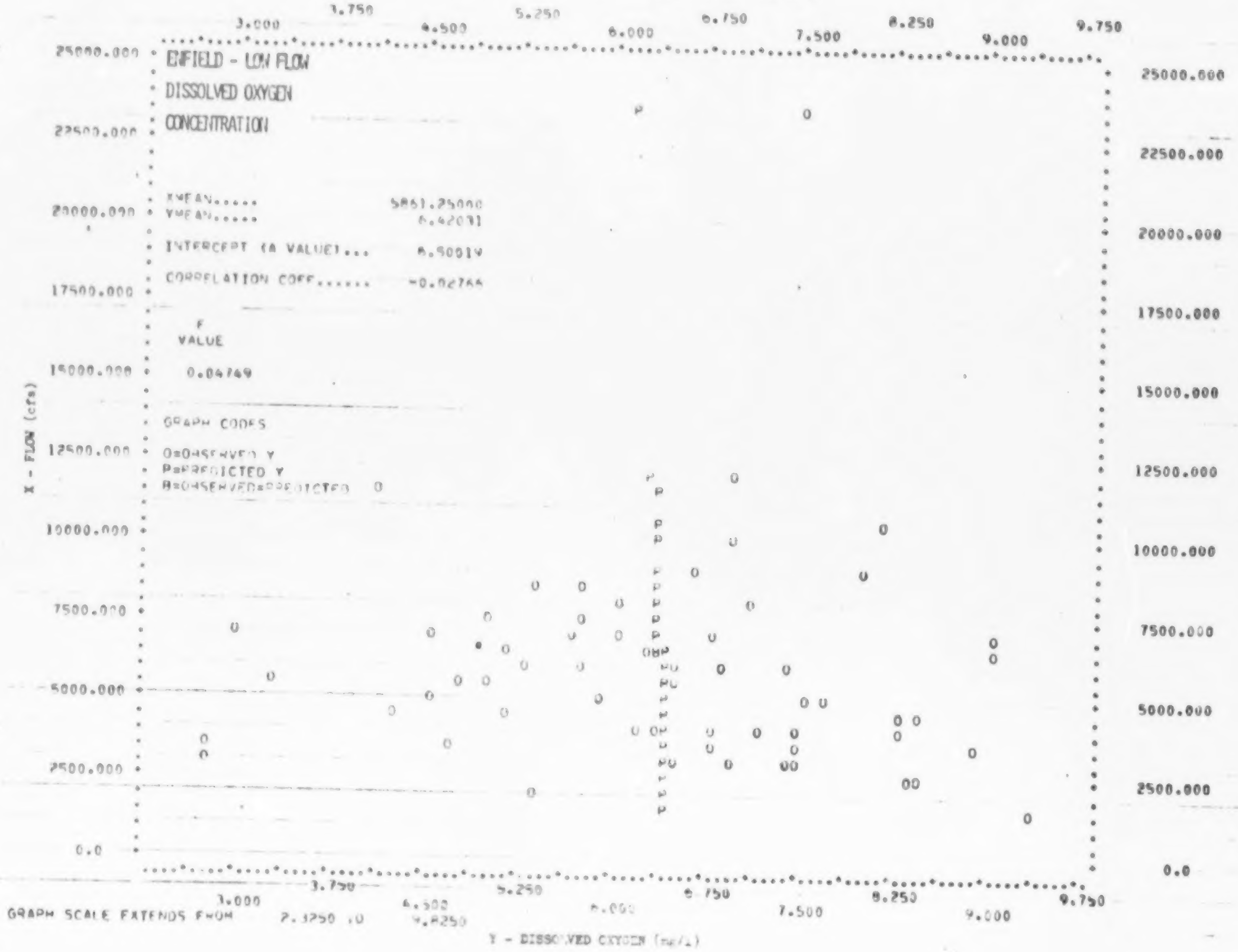
PLOT OF OBSERVED AND PREDICTED VALUES.



```
ENFIELD - HIGH FLOW
DISSOLVED OXYGEN
CONCENTRATION

XMEAN.....              25862.58065
YMEAN.....                 10.78710

INTERCEPT (A VALUE)...      9.44525

CORRELATION COEF.......     0.50669

 F
 VALUE

 20.72432

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 5.6000 TO 15.6000

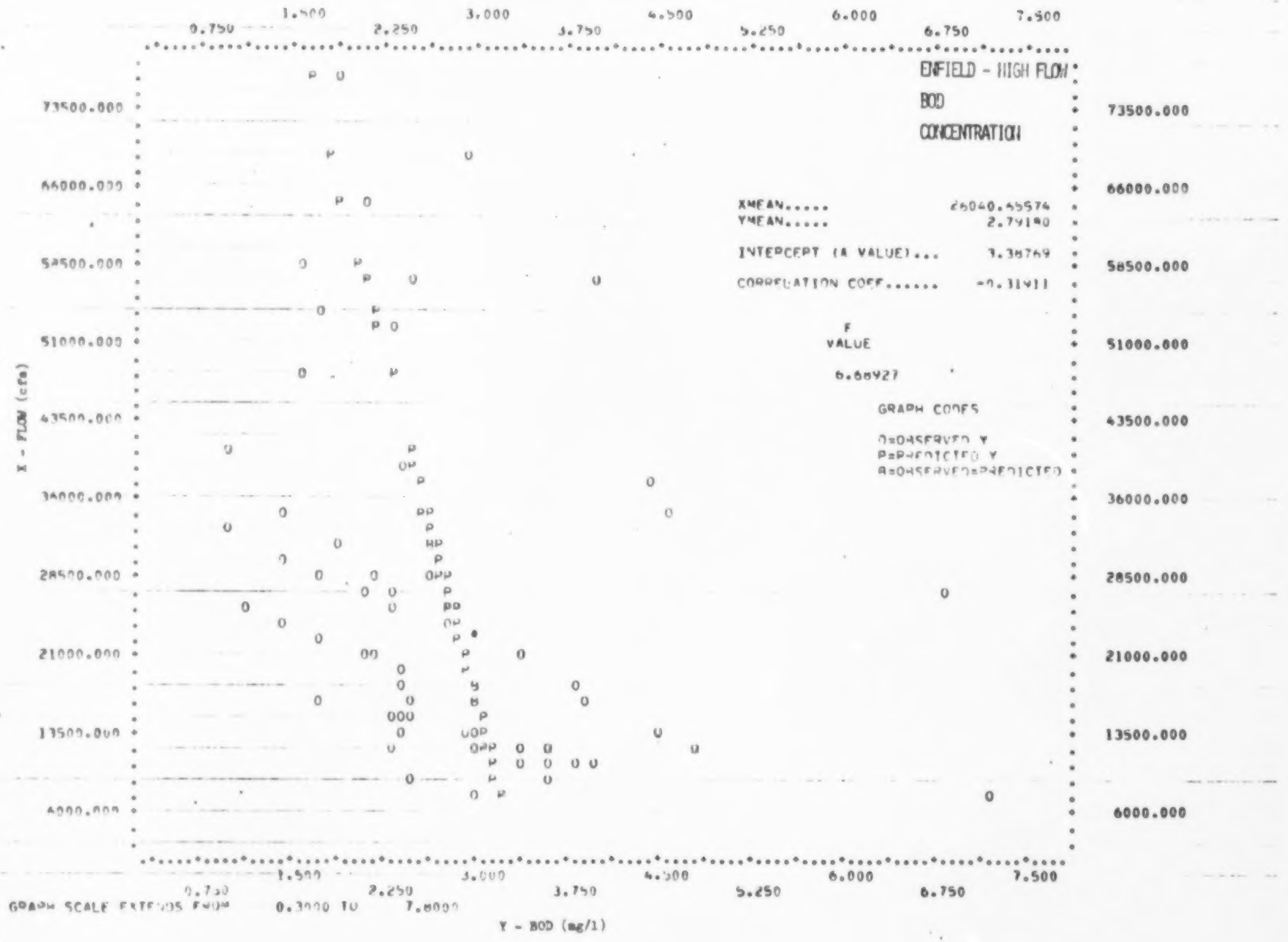
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                 5861.25000
YMEAN.....                    6.42031

INTERCEPT (A VALUE)...        6.50019

CORRELATION COEFF......      -0.02766

  F
 VALUE

  0.04749

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED   0
```

GRAPH SCALE EXTENDS FROM 2.3250 TO 9.8250

PLOT OF OBSERVED AND PREDICTED VALUES.

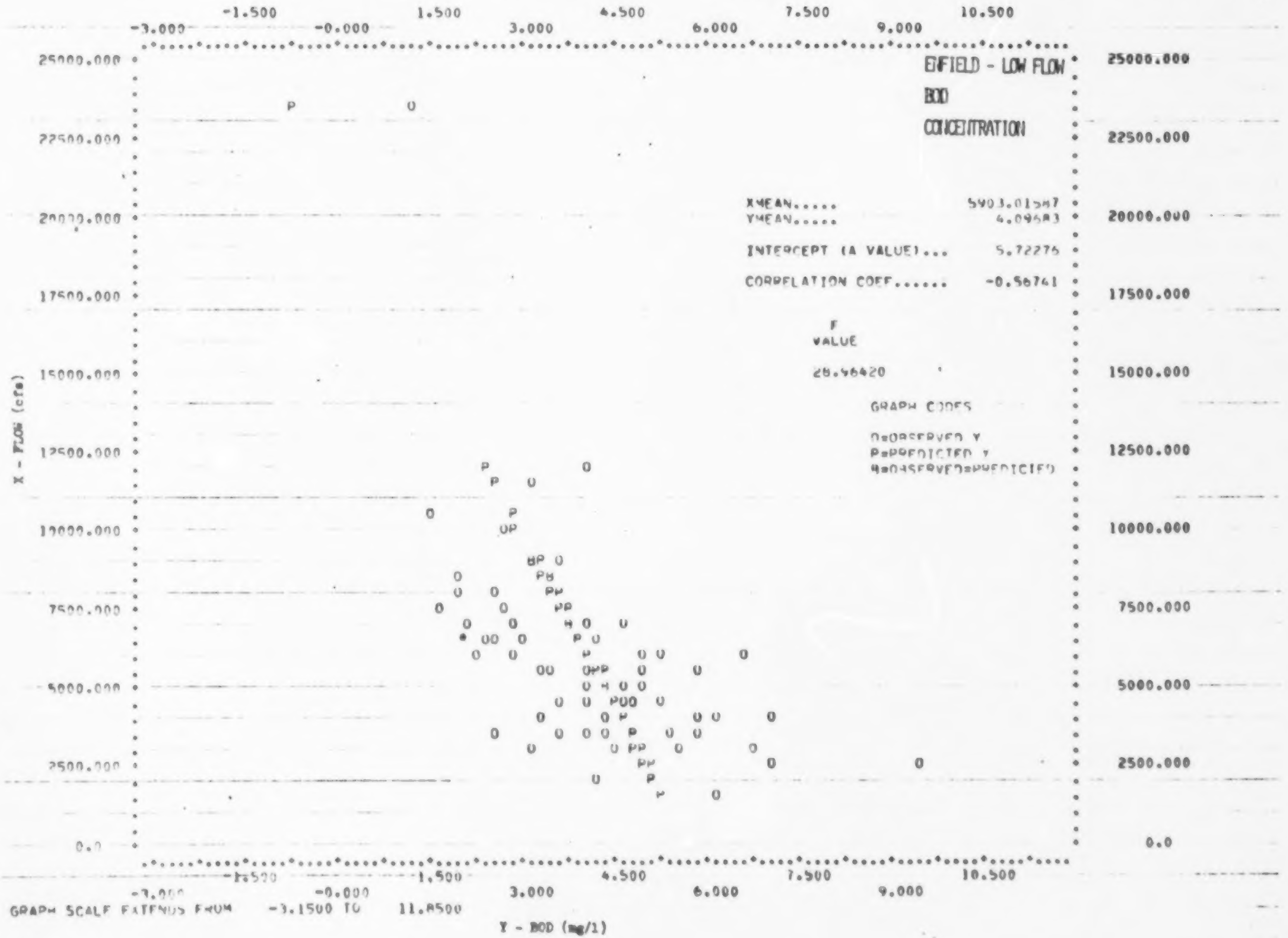


ENFIELD - HIGH FLOW
BOD
CONCENTRATION

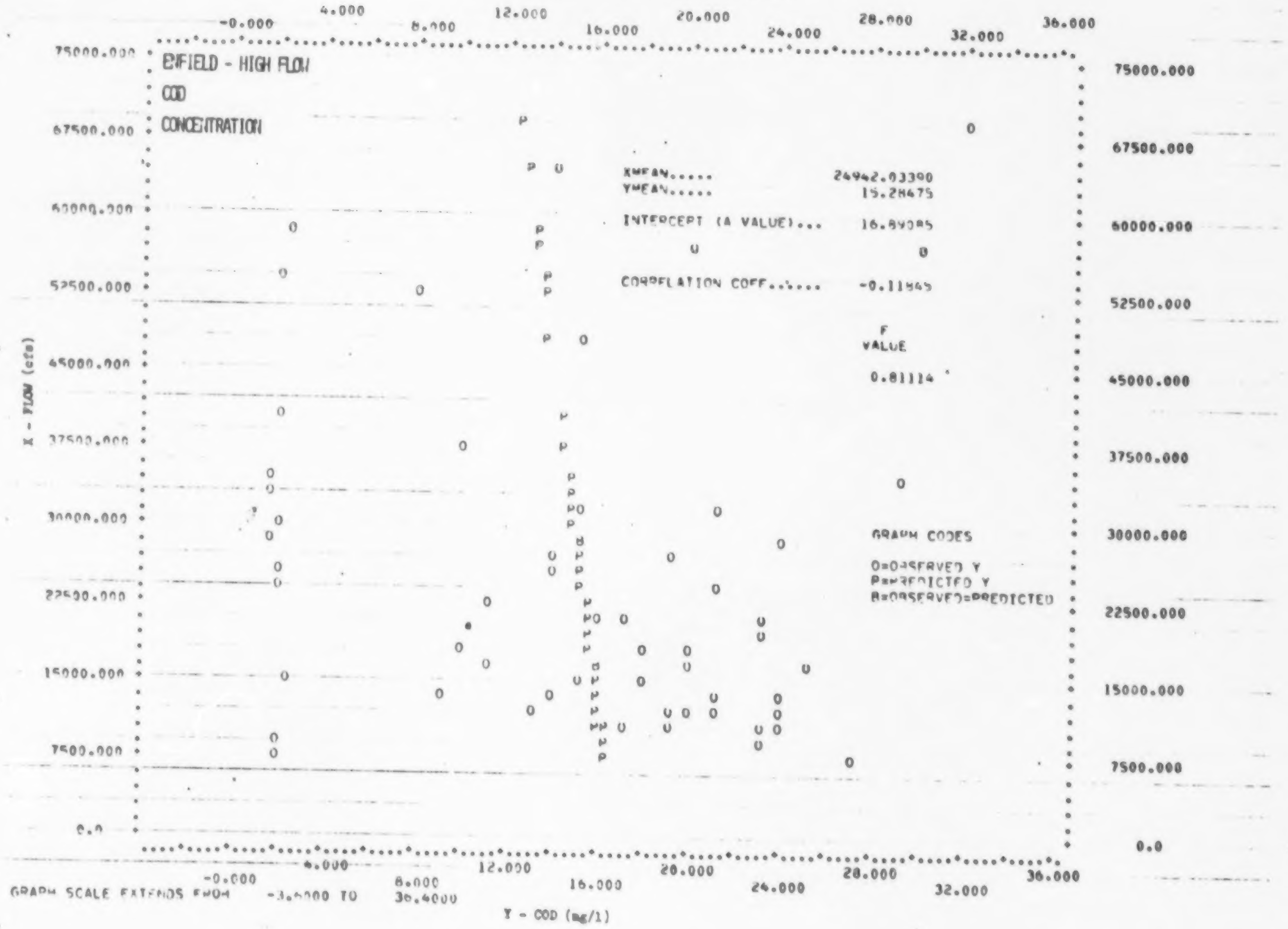
```
XMEAN.....                26040.55574
YMEAN.....                    2.79190

INTERCEPT (A VALUE)...        3.38769

CORRELATION COFF......       -0.31911

        F
      VALUE

      6.68927

          GRAPH CODES

          O=OBSERVED Y
          P=PREDICTED Y
          B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM   0.3000 TO   7.8000

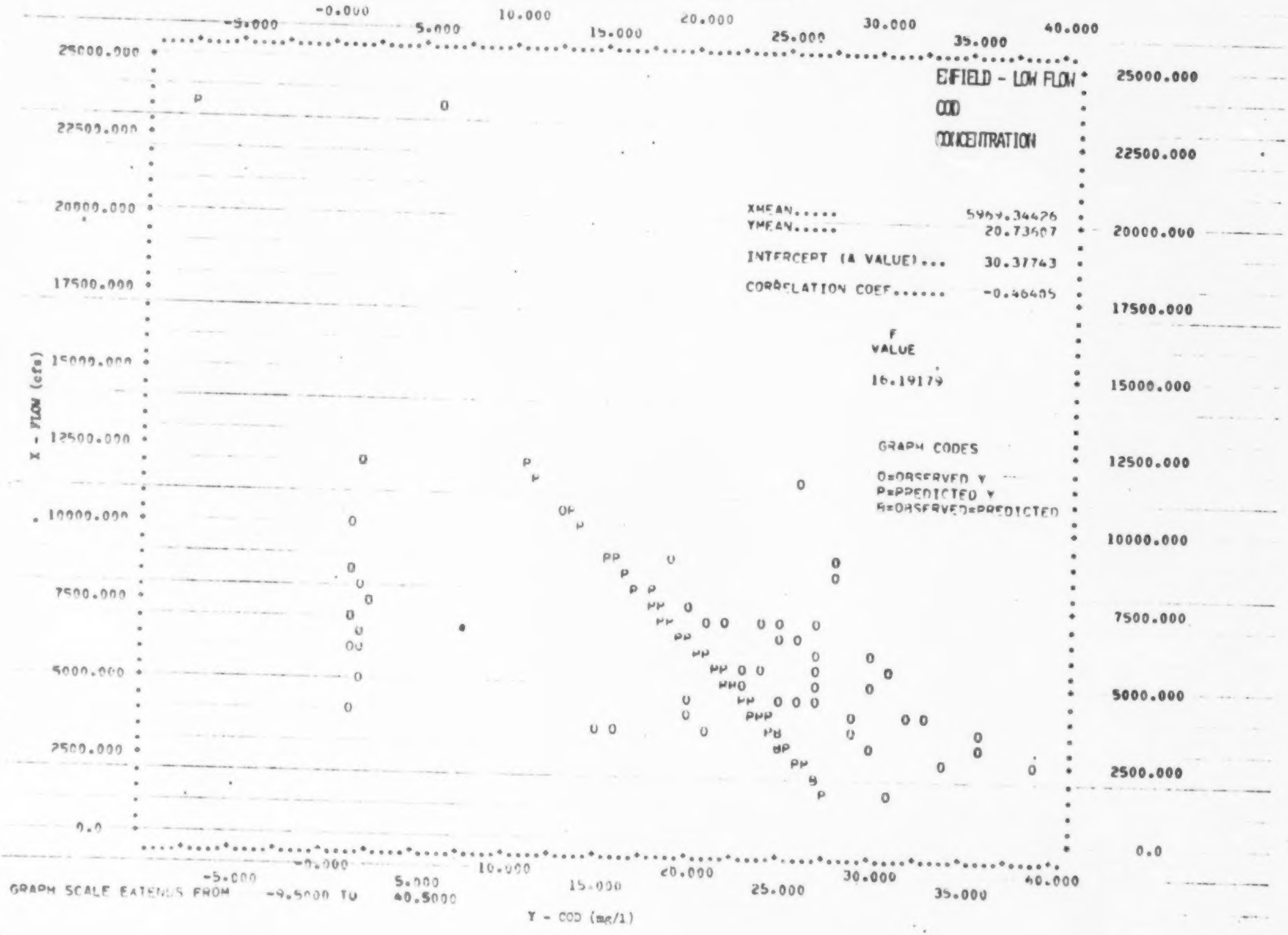
PLOT OF OBSERVED AND PREDICTED VALUES.



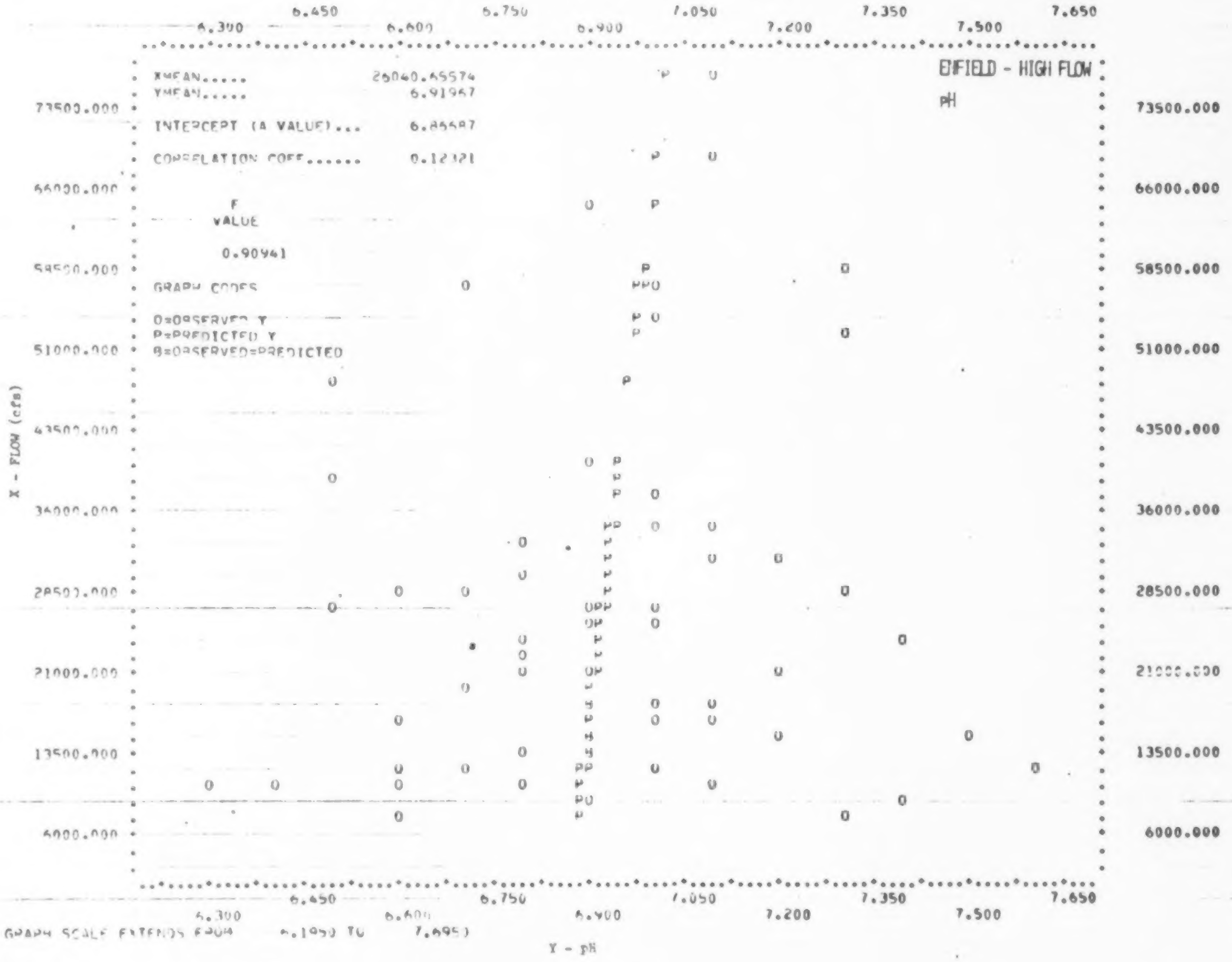
PLOT OF OBSERVED AND PREDICTED VALUES.



PLOT OF OBSERVED AND PREDICTED VALUES.

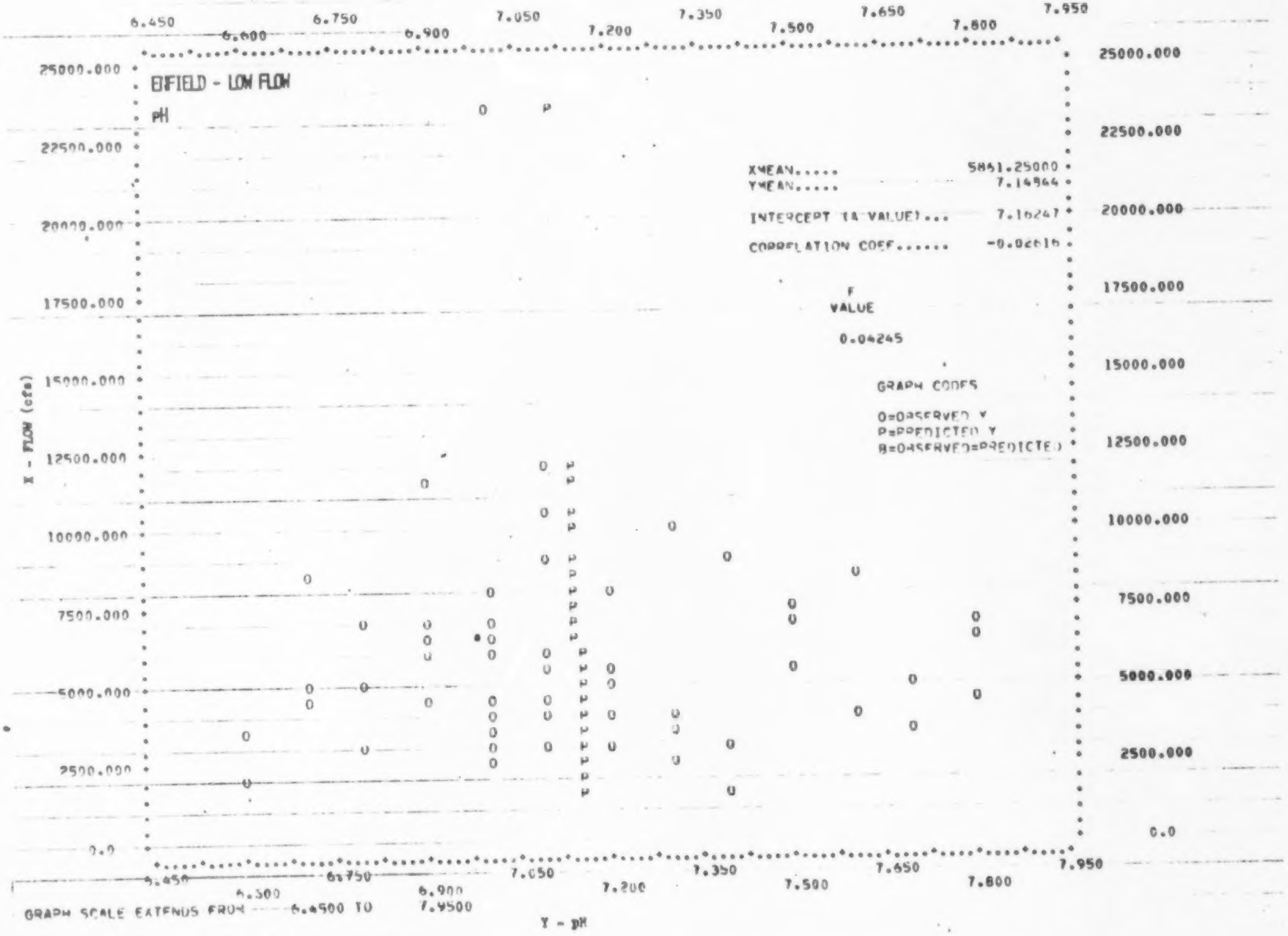


PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....              26040.65574
YMEAN.....                  6.91967

INTERCEPT (A VALUE)...      6.85587

CORRELATION COEF......      0.12121

        F
      VALUE

     0.90941

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM    6.1950 TO    7.6950
```

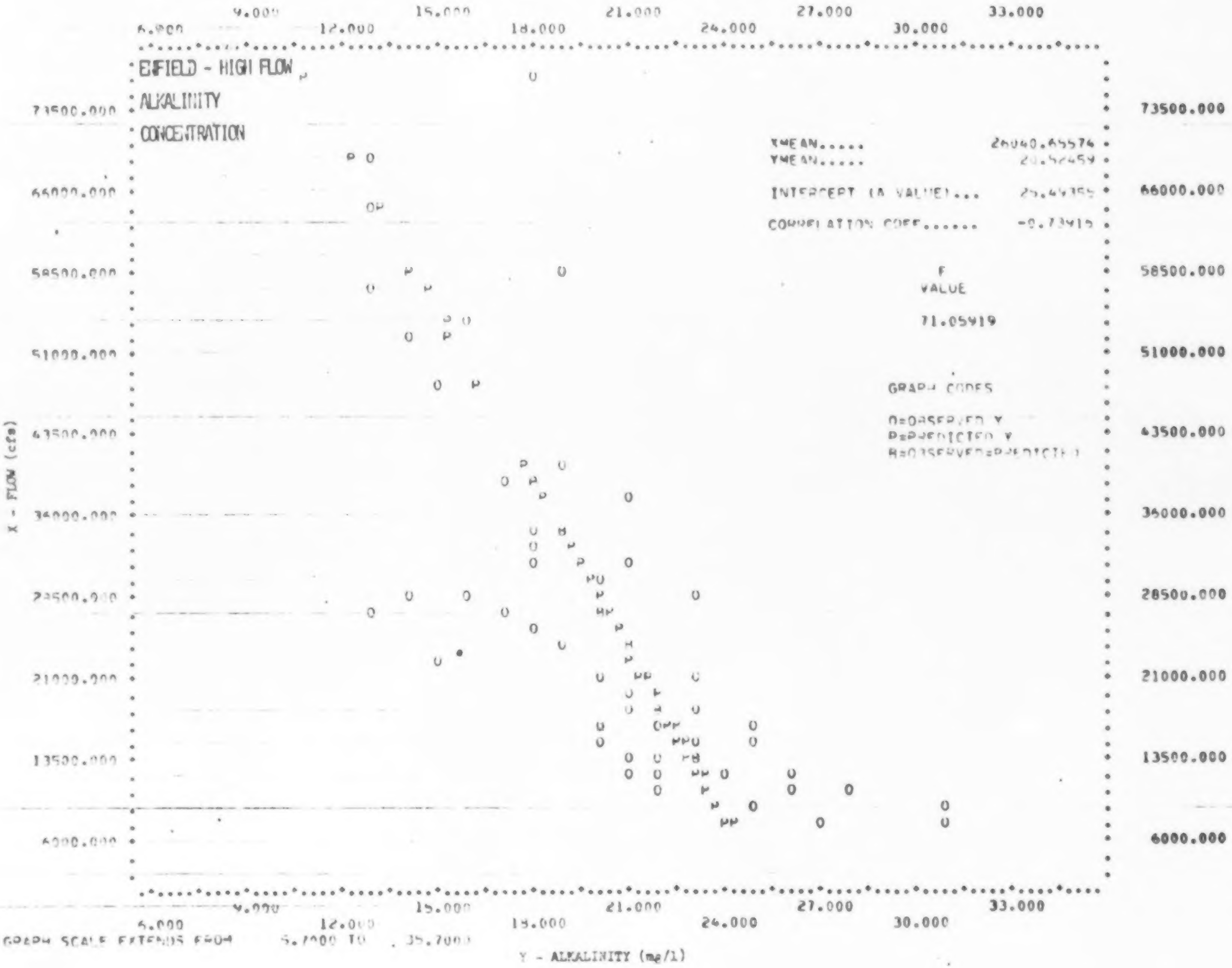
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                 5861.25000
YMEAN.....                    7.14944
INTERCEPT (A VALUE)...        7.16247
CORRELATION COEF......       -0.02616

          F
        VALUE

       0.04245

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 6.4500 TO 7.9500

PLOT OF OBSERVED AND PREDICTED VALUES.



XMEAN..... 26040.65574
YMEAN..... 20.52459

INTERCEPT (A VALUE)... 25.44355

CORRELATION COEF....... -0.73415

F
VALUE

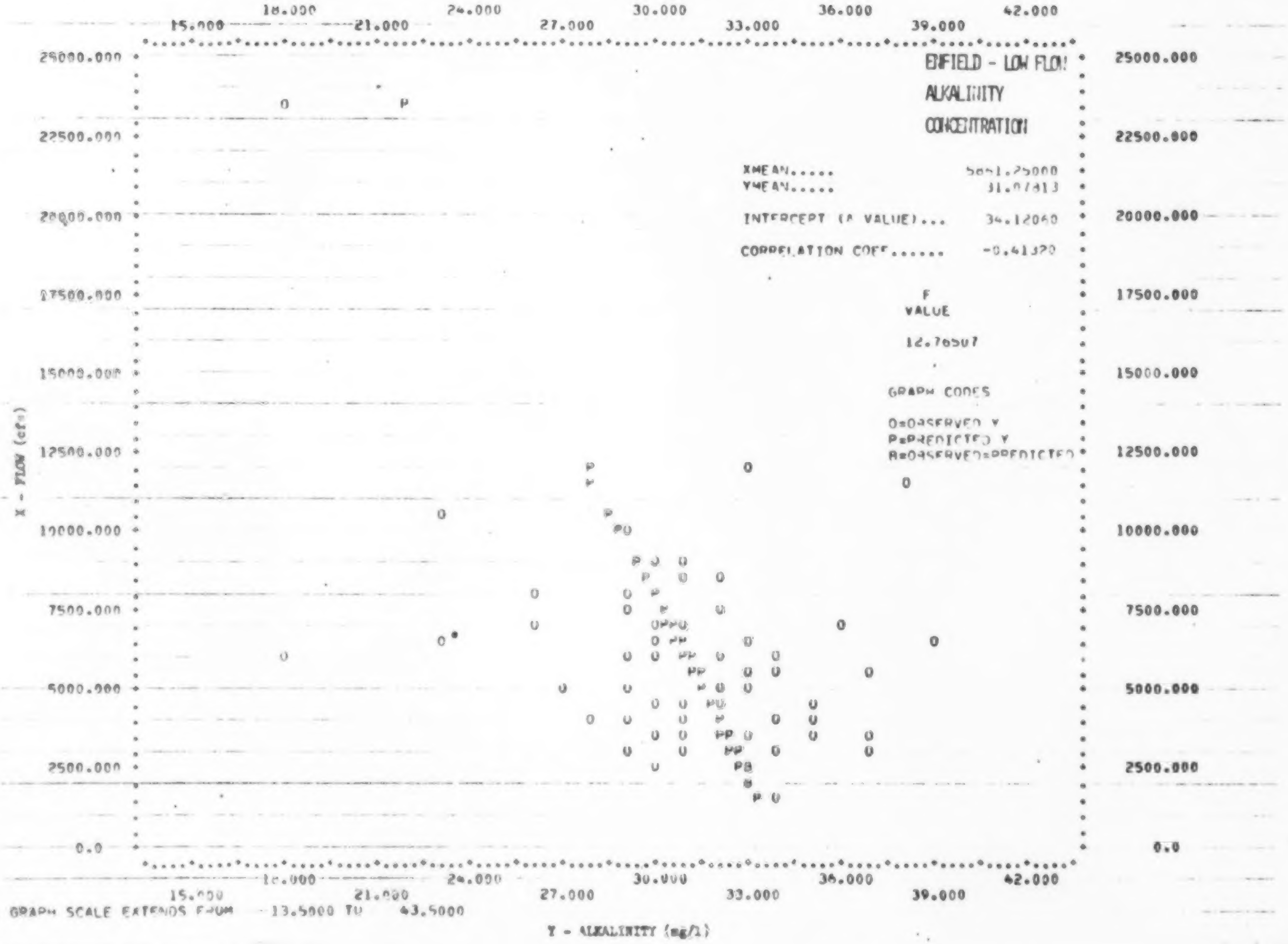
71.05919

GRAPH CODES

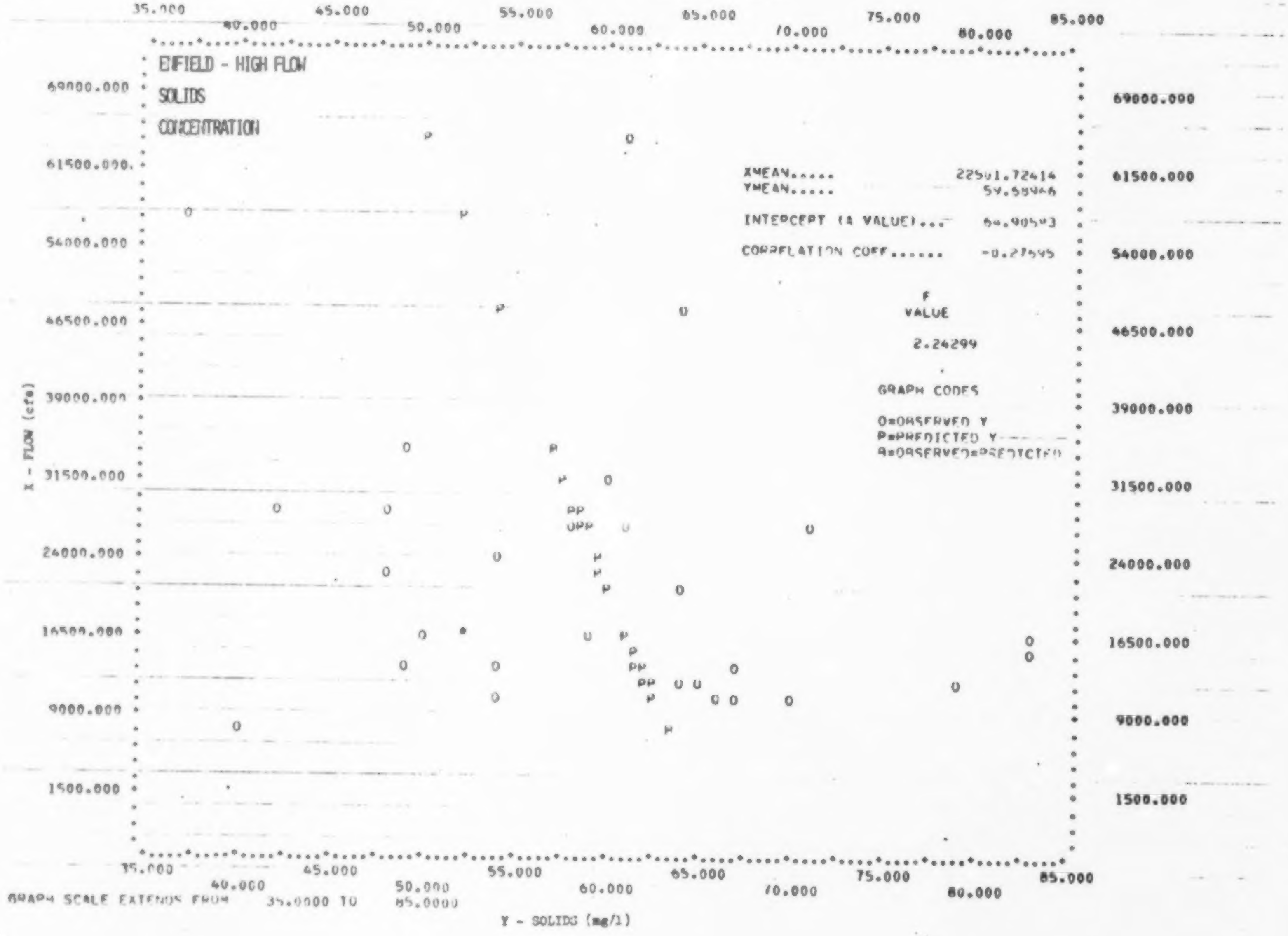
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM 5.7000 TO 35.7000

PLOT OF OBSERVED AND PREDICTED VALUES.



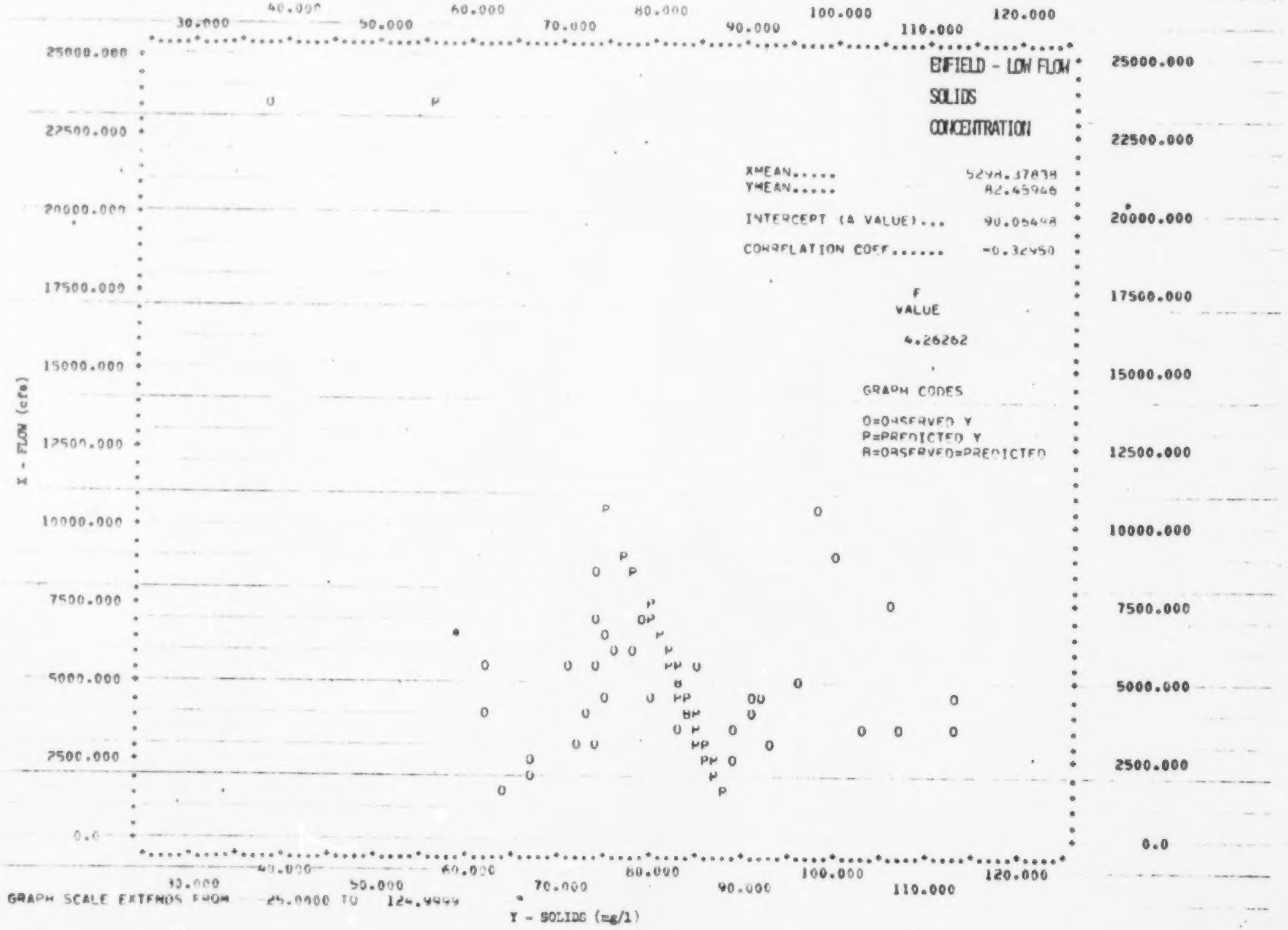
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                22501.72414
YMEAN.....                   59.55946

INTERCEPT (A VALUE)...       64.90593

CORRELATION COEF......       -0.27595

                F
              VALUE

             2.24299

          GRAPH CODES

          O=OBSERVED Y
          P=PREDICTED Y
          B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 35.0000 TO 85.0000

PLOT OF OBSERVED AND PREDICTED VALUES.



ENFIELD - LOW FLOW

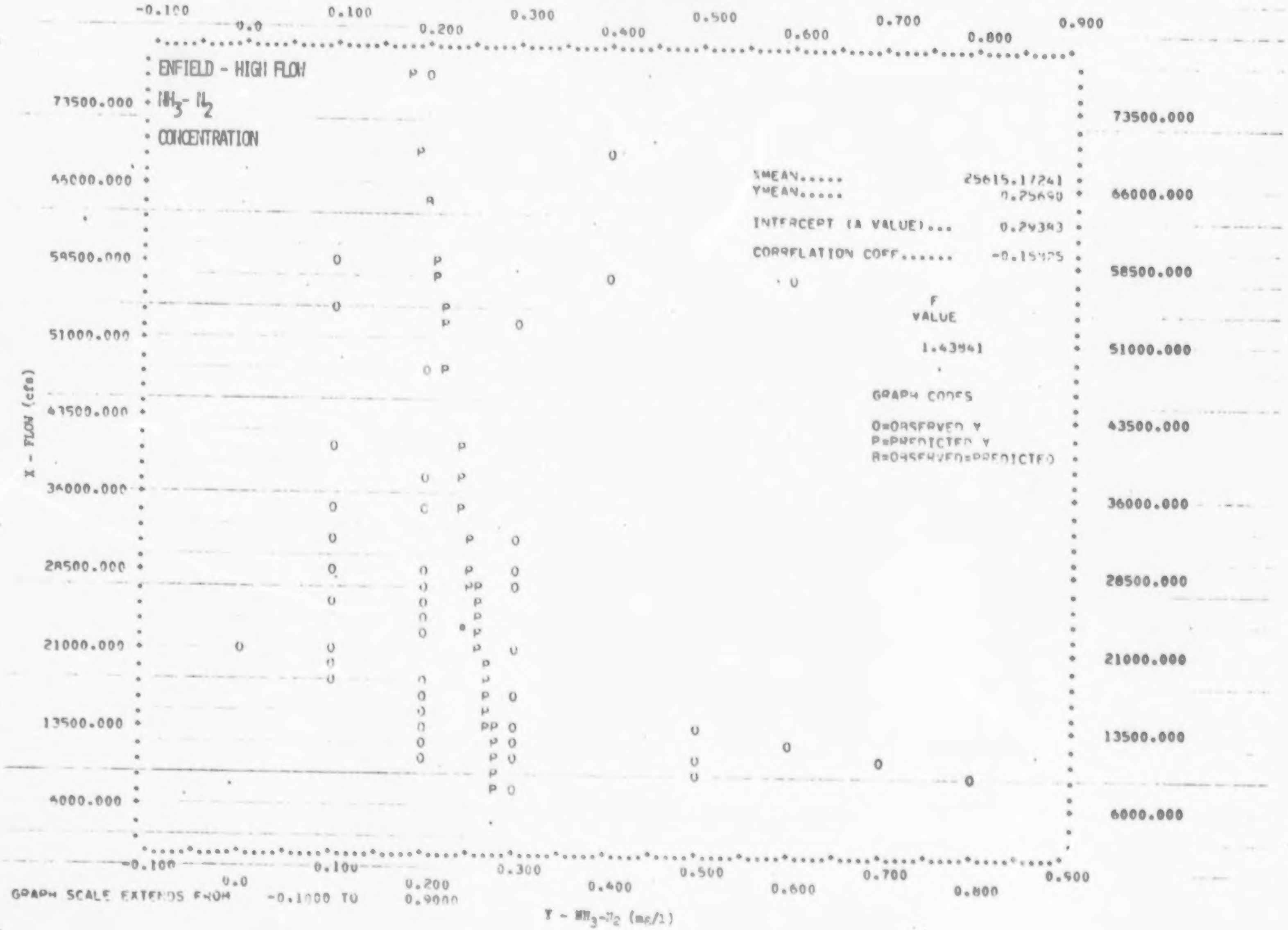
SOLIDS

CONCENTRATION

```
XMEAN.....                 5298.37838
YMEAN.....                   82.45946

INTERCEPT (A VALUE)...       90.05498

CORRELATION COEF......       -0.32950

       F
     VALUE

    4.26262

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 25.0000 TO 124.9999

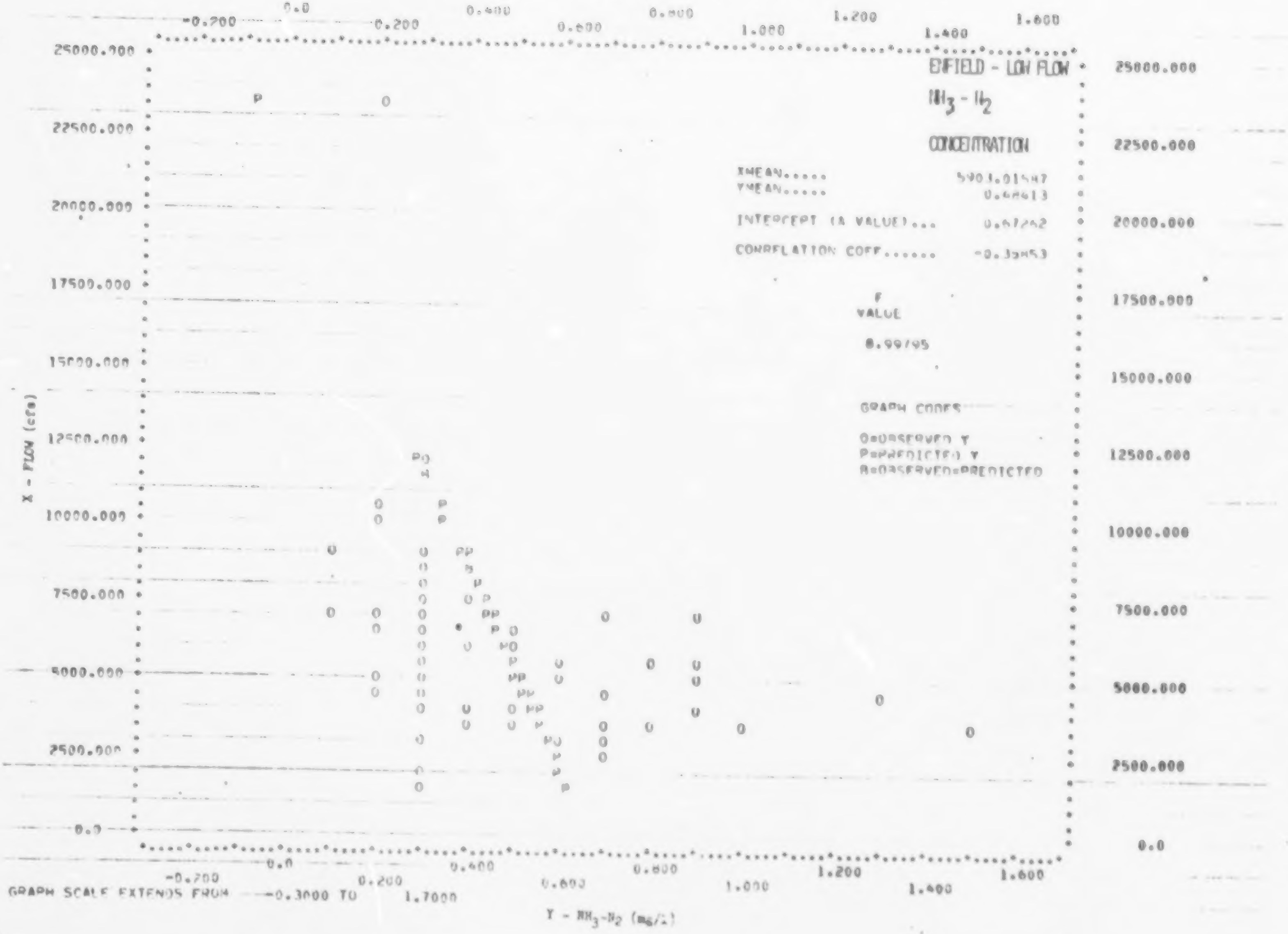
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                    25615.17241
YMEAN.....                        0.25690

INTERCEPT (A VALUE)...            0.29393

CORRELATION COFF......           -0.15925

                      F
                    VALUE

                   1.43941

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
R=OBSERVED=PREDICTED
```

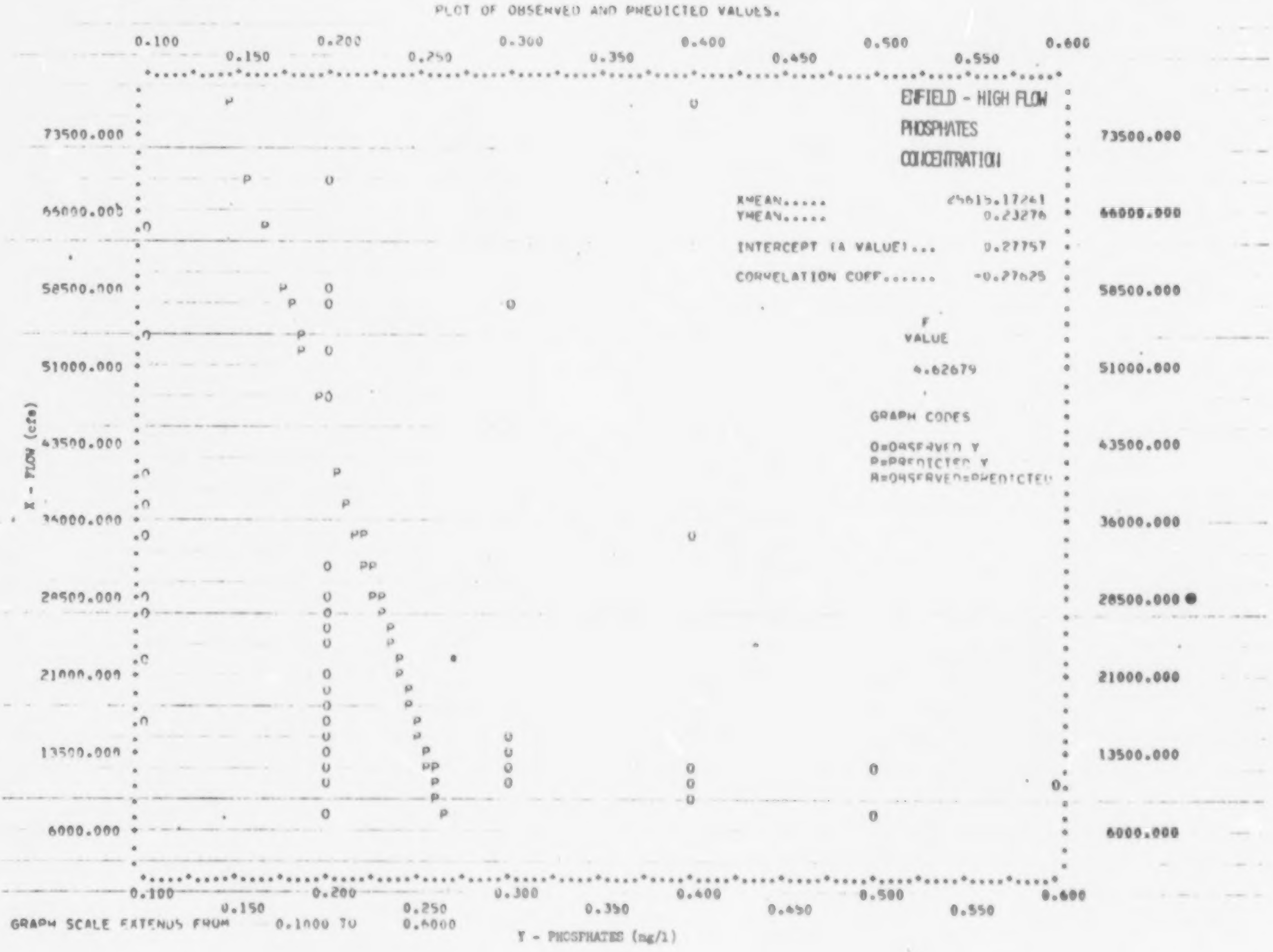
GRAPH SCALE EXTENDS FROM -0.1000 TO 0.9000

PLOT OF OBSERVED AND PREDICTED VALUES.

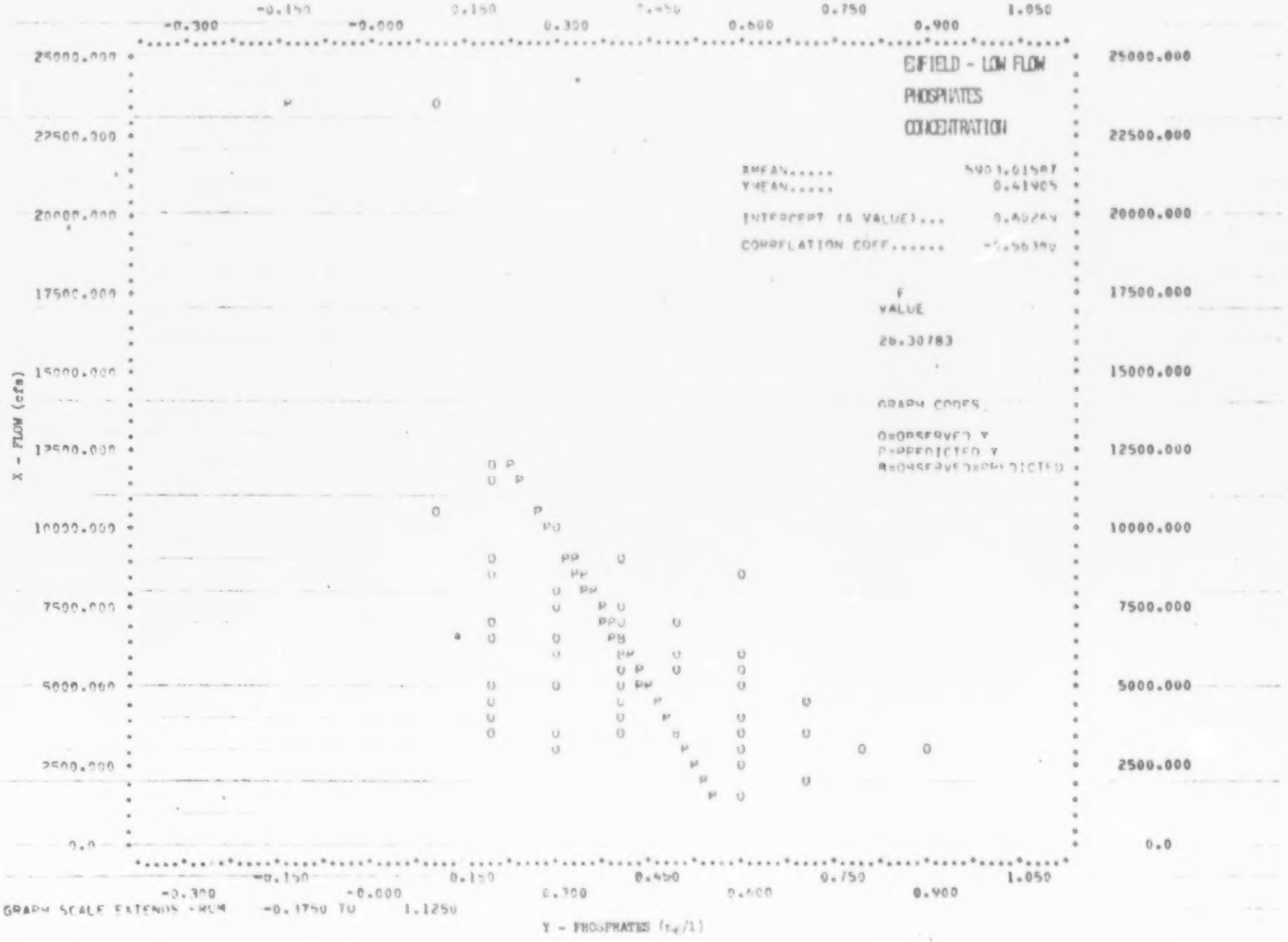


```
XMEAN.....                 5903.01587
YMEAN.....                    0.66613

INTERCEPT (A VALUE)...        0.67262

CORRELATION COFF.......      -0.35853

             F
           VALUE

          8.99795


        GRAPH CODES

        O=OBSERVED Y
        P=PREDICTED Y
        B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM -0.3000 TO 1.7000

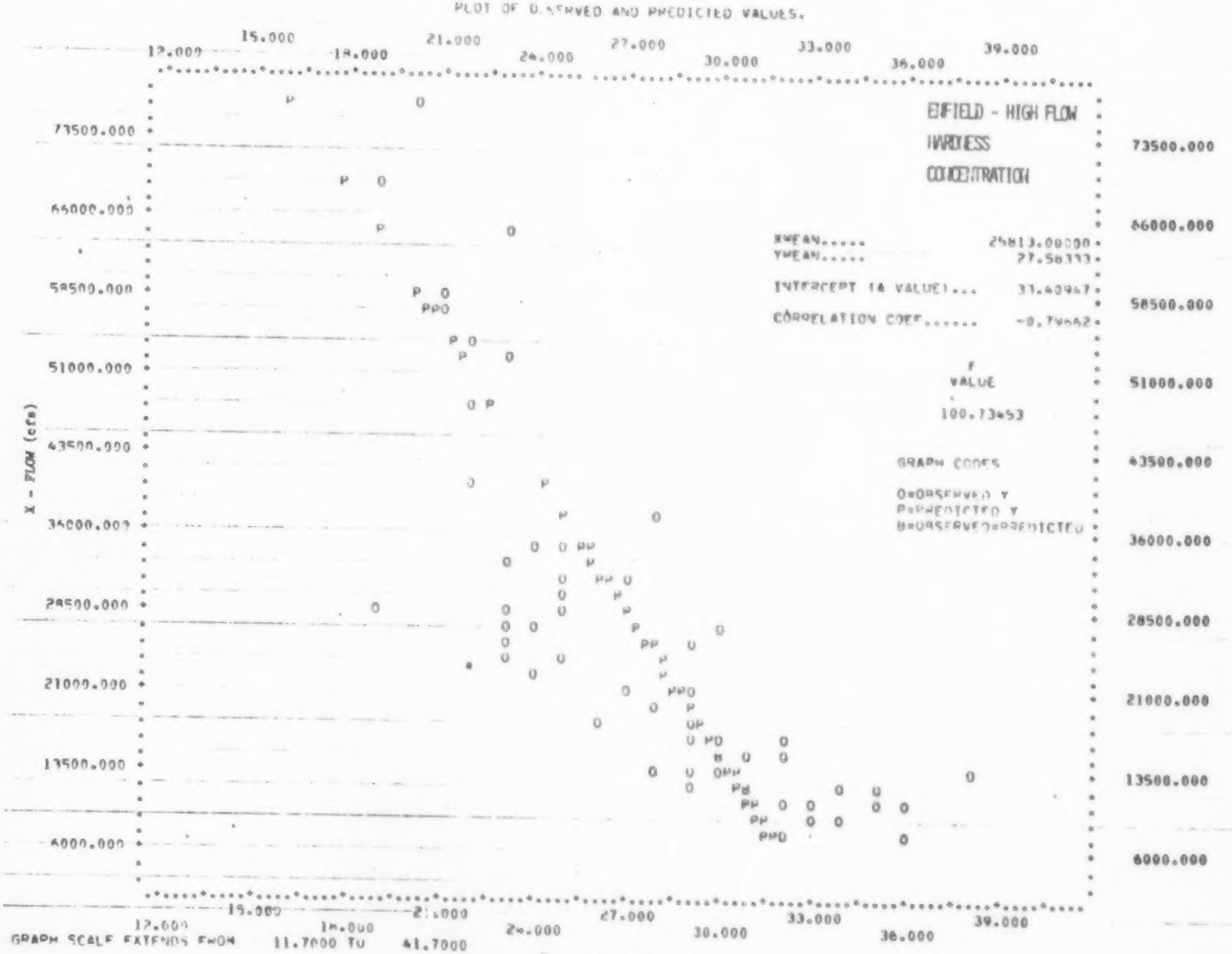

PLOT OF OBSERVED AND PREDICTED VALUES.
ENFIELD - HIGH FLOW
PHOSPHATES
CONCENTRATION
XMEAN..... 25615.17261
YMEAN..... 0.23276
INTERCEPT (A VALUE)... 0.27757
CORRELATION COFF...... -0.27625
F
VALUE
4.62679
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
R=OBSERVED=PREDICTED
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
0.550
0.600
73500.000
66000.000
58500.000
51000.000
43500.000
36000.000
28500.000
21000.000
13500.000
6000.000
X - FLOW (cfs)
Y - PHOSPHATES (mg/l)
GRAPH SCALE EXTENDS FROM 0.1000 TO 0.6000

PLOT OF OBSERVED AND PREDICTED VALUES.



GRAPH SCALE EXTENDS FROM -0.1750 TO 1.1250

PLOT OF OBSERVED AND PREDICTED VALUES.

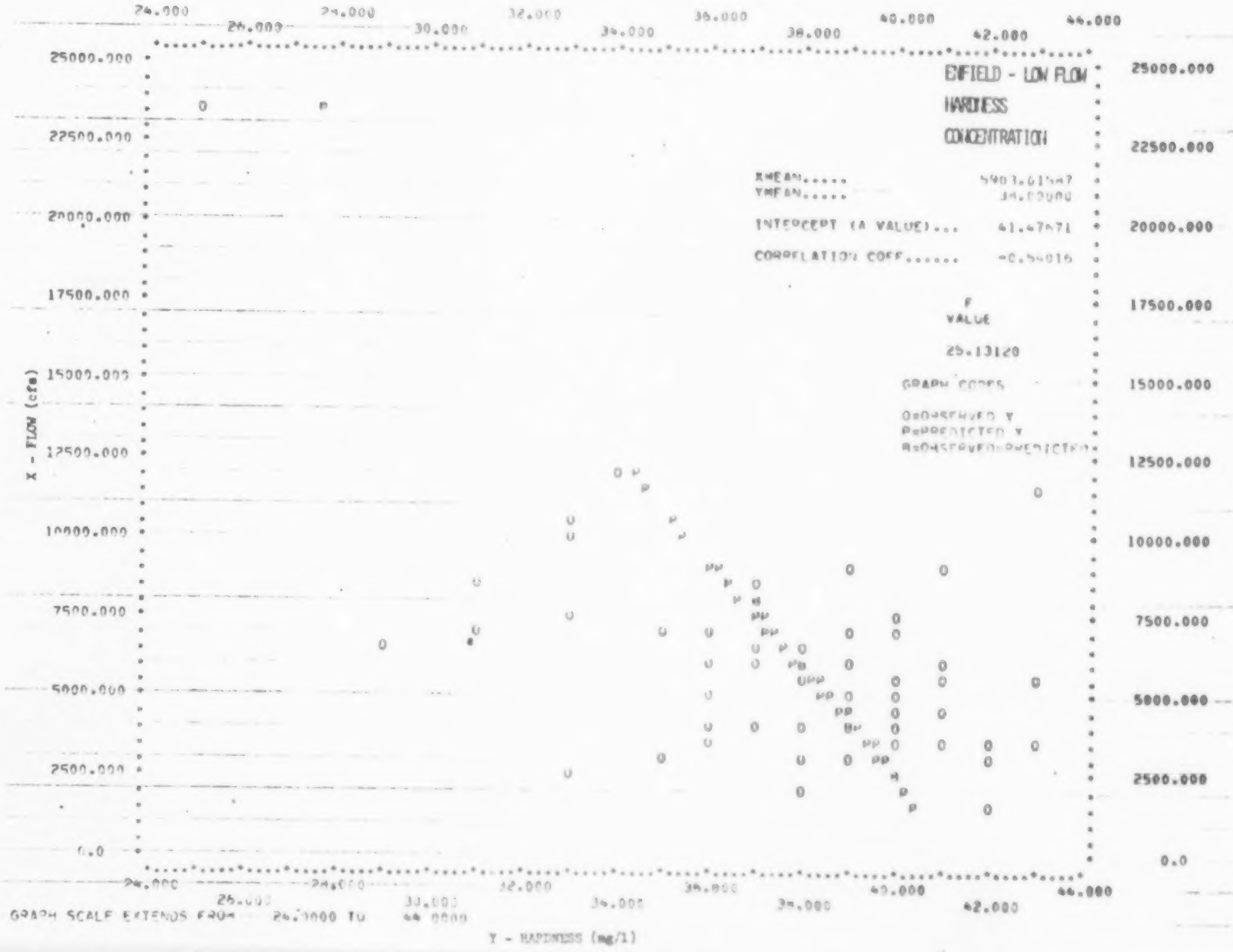


ENFIELD - HIGH FLOW
HARDNESS
CONCENTRATION

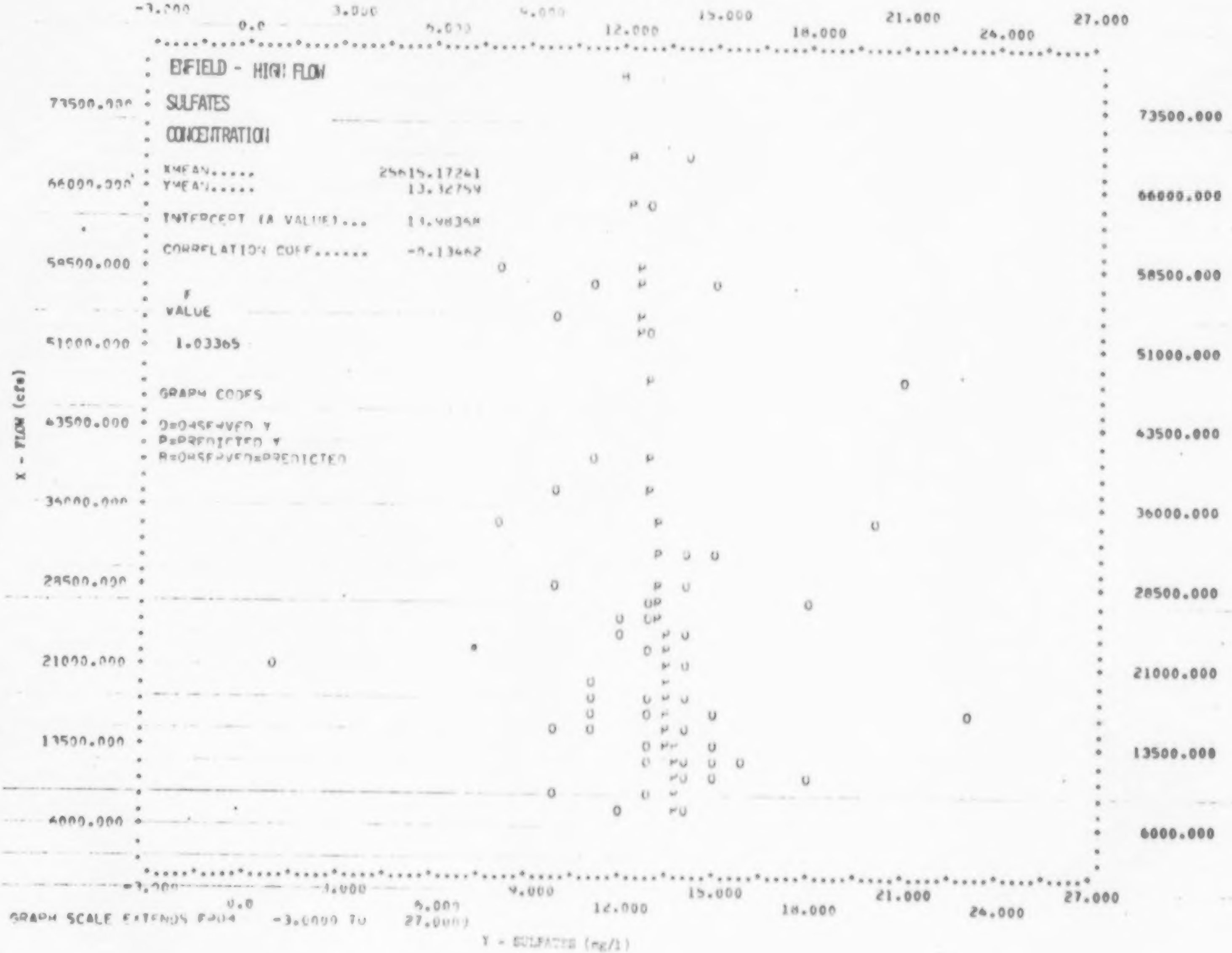
```
XMEAN.....                 25813.00000
YMEAN.....                    27.58333

INTERCEPT (A VALUE)...        31.40947

CORRELATION COEF.......       -0.79662

                F
              VALUE
                .
            100.73453

           GRAPH CODES

           O=OBSERVED Y
           P=PREDICTED Y
           B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 11.7000 TO 41.7000

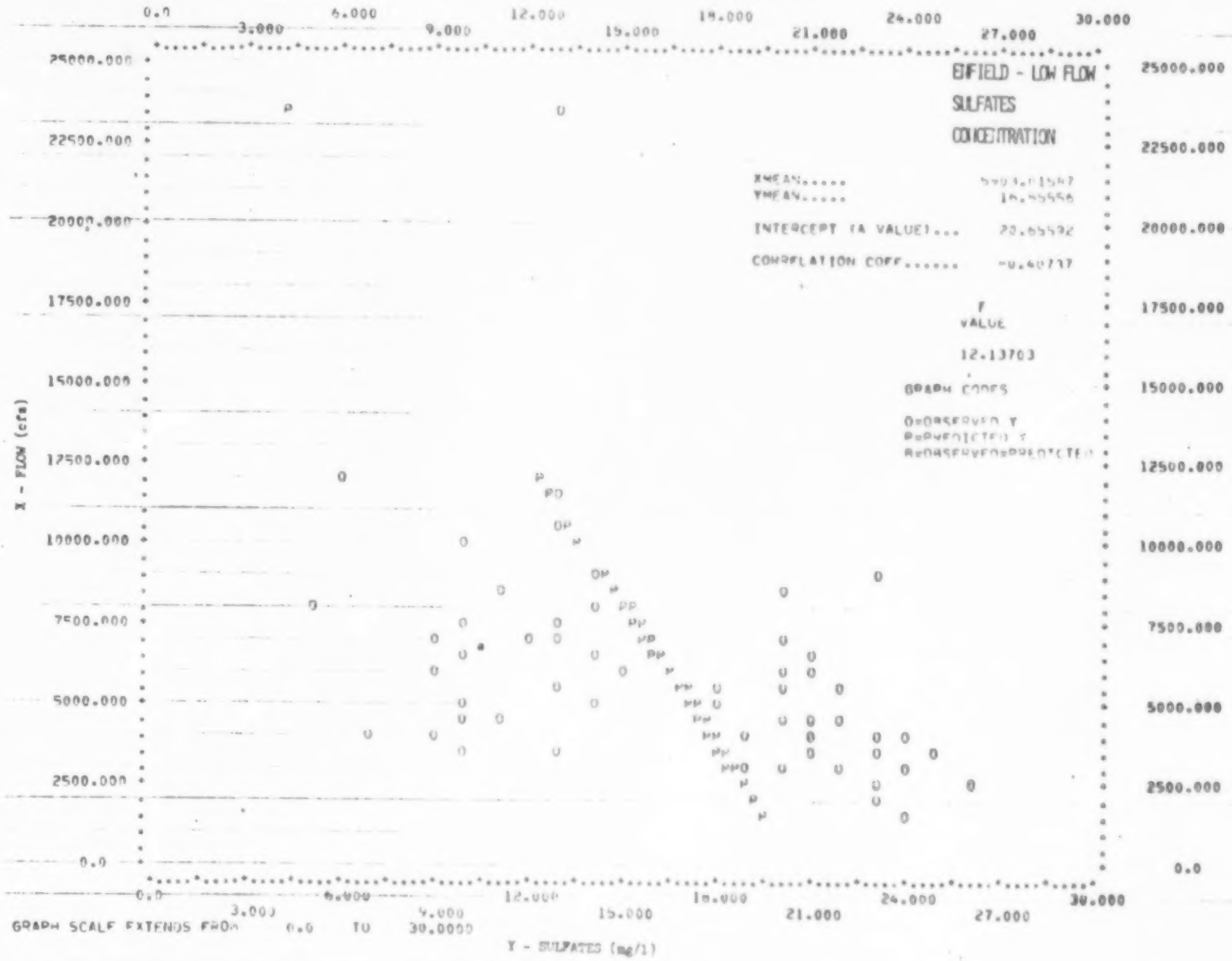
PLOT OF OBSERVED AND PREDICTED VALUES.



PLOT OF OBSERVED AND PREDICTED VALUES.



PLOT OF OBSERVED AND PREDICTED VALUES.

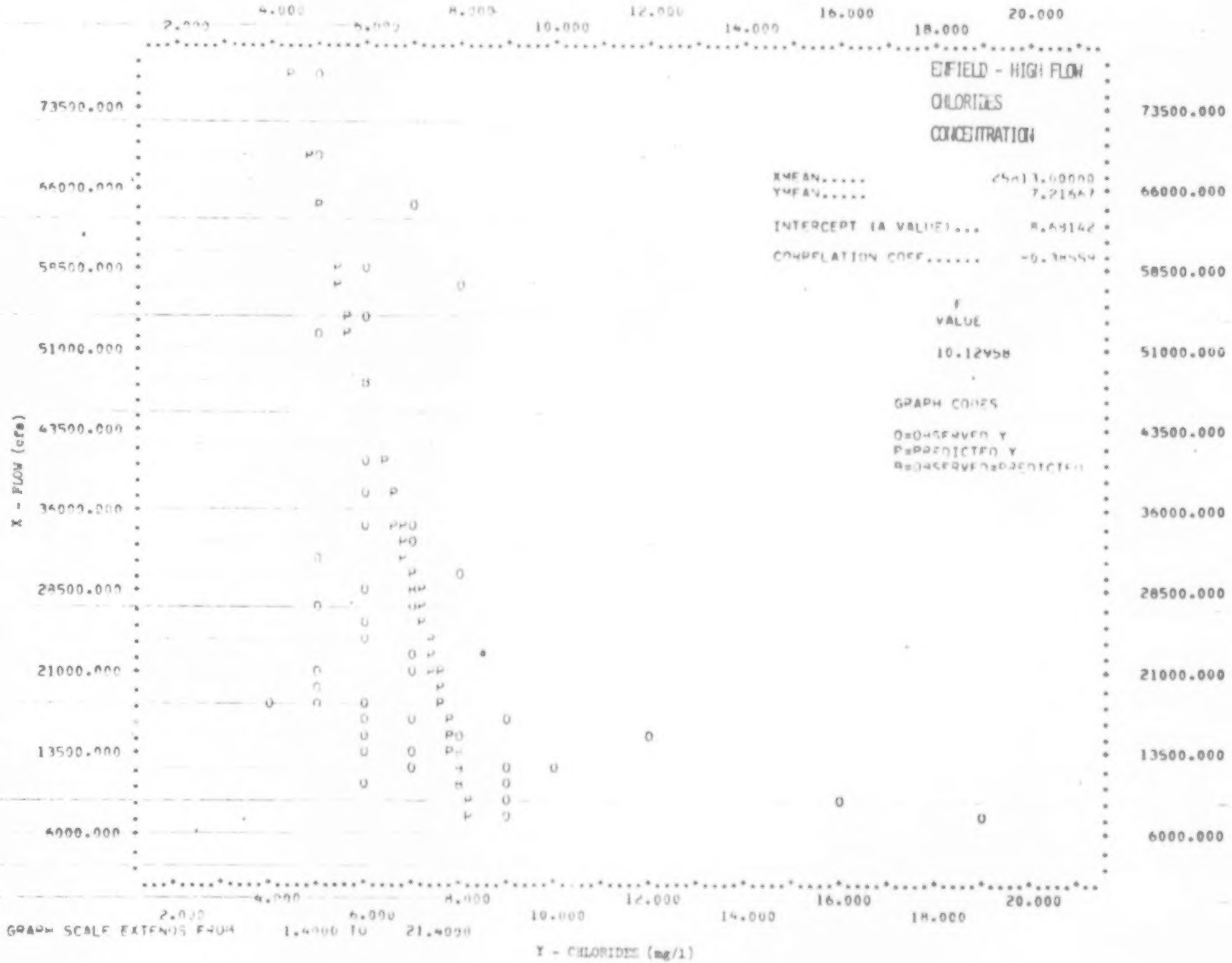


ENFIELD - LOW FLOW
SULFATES
CONCENTRATION

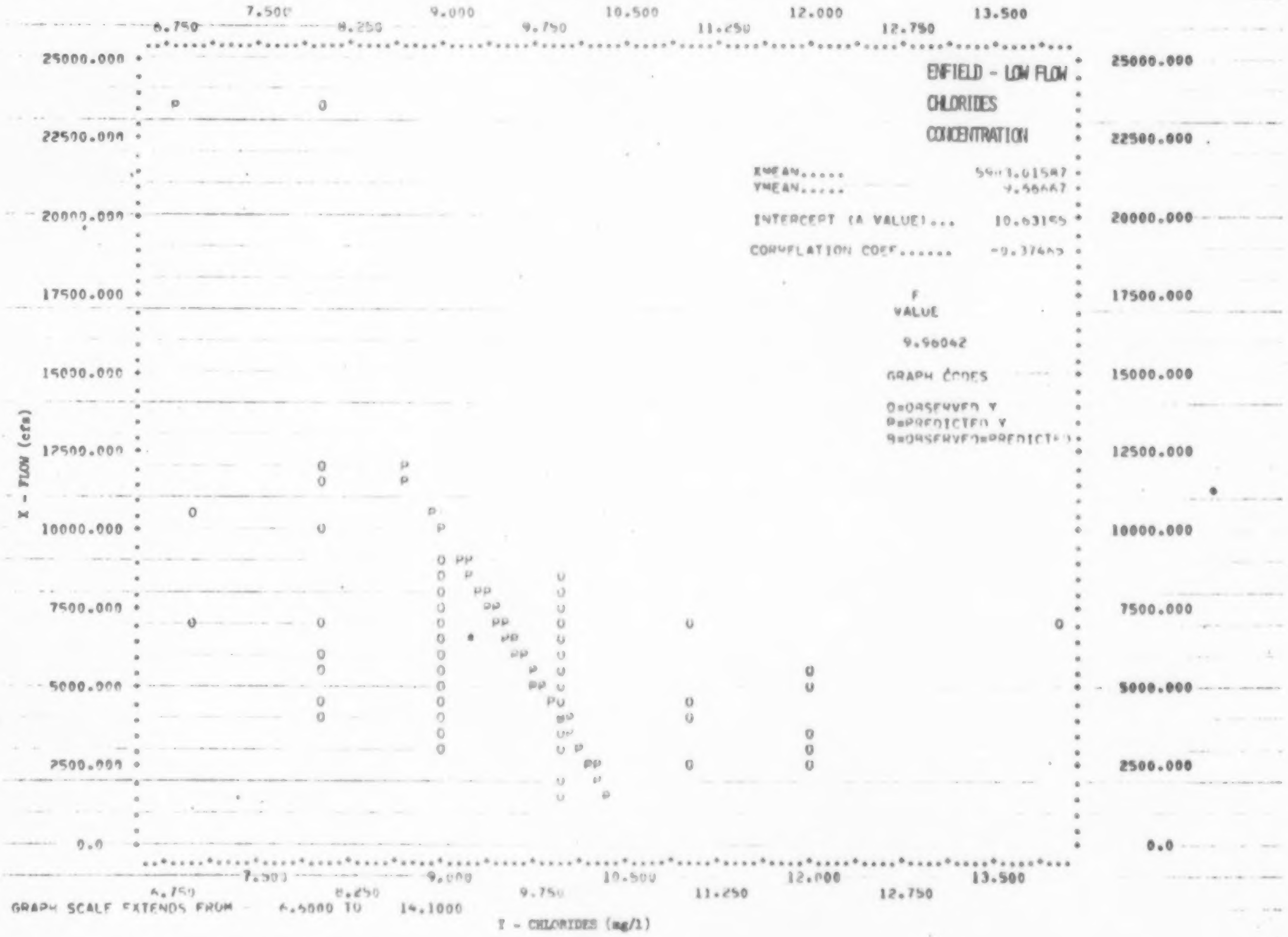
```
XMEAN.....        5903.01587
YMEAN.....          16.55556

INTERCEPT (A VALUE)...    20.65532

CORRELATION COEF......    -0.40737

              F
            VALUE

           12.13703

        GRAPH CODES

        O=OBSERVED Y
        P=PREDICTED Y
        B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 0.0 TO 30.0000

PLOT OF OBSERVED AND PREDICTED VALUES.



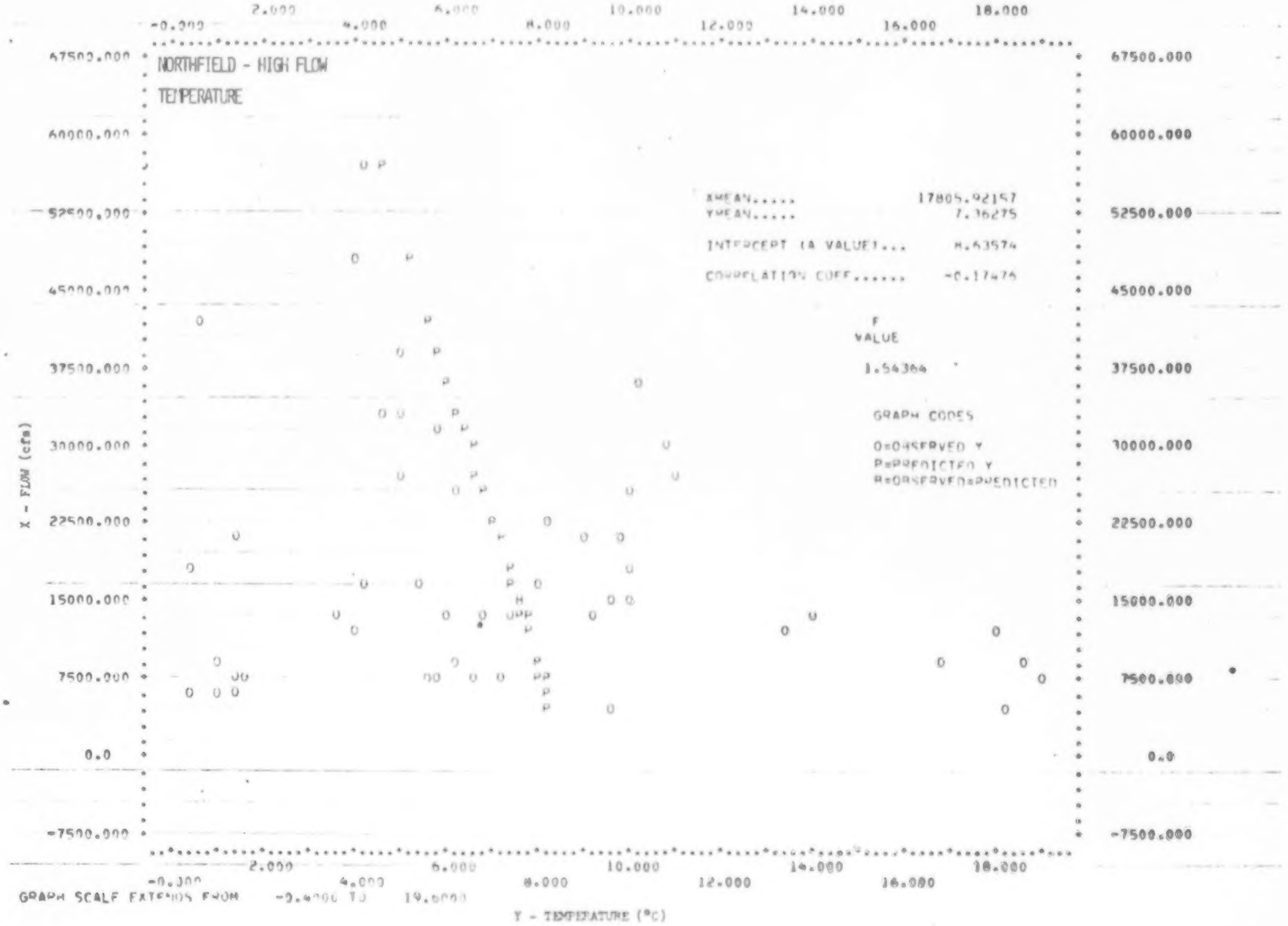
PLOT OF OBSERVED AND PREDICTED VALUES.



```
ENFIELD - LOW FLOW
CHLORIDES
CONCENTRATION

XMEAN.....                 5903.01587
YMEAN.....                    9.56667

INTERCEPT (A VALUE)...       10.63155

CORRELATION COEF......       -0.37465

                F
              VALUE

             9.96042

           GRAPH CODES

           O=OBSERVED Y
           P=PREDICTED Y
           9=OBSERVED=PREDICTED
```

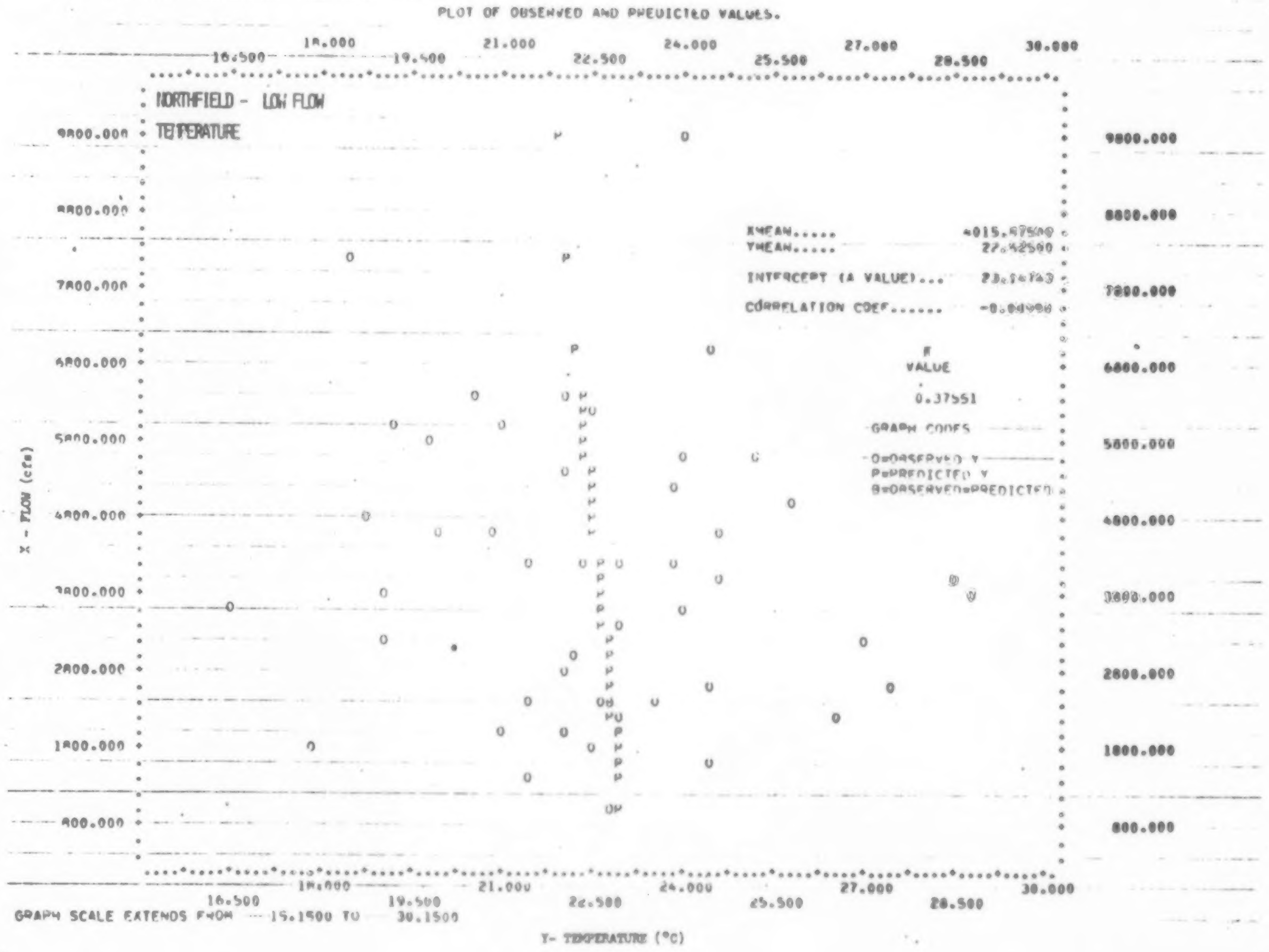
GRAPH SCALE EXTENDS FROM 6.5000 TO 14.1000

PLOT OF OBSERVED AND PREDICTED VALUES.

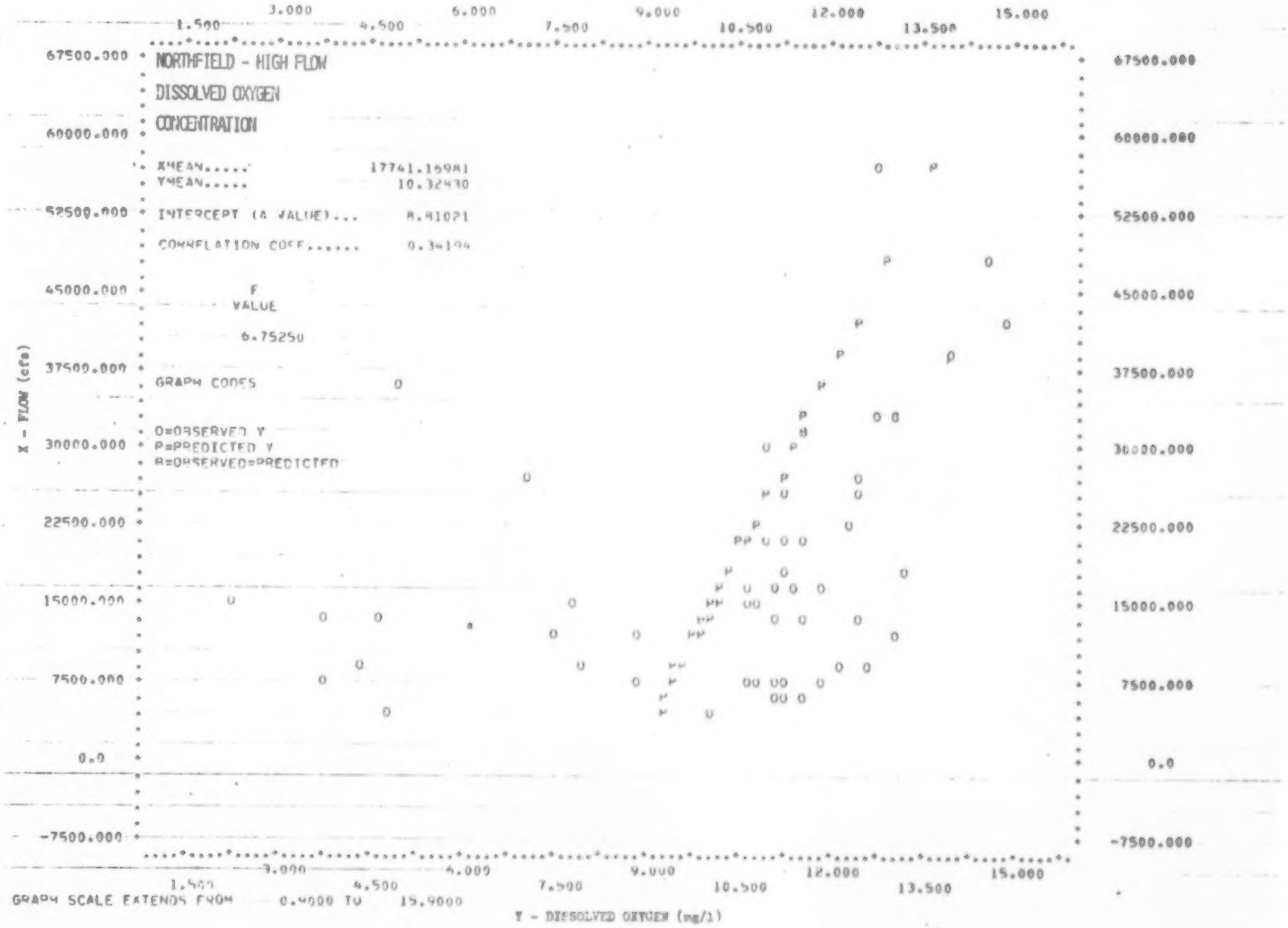


```
XMEAN.....                17805.92157
YMEAN.....                    7.36275

INTERCEPT (A VALUE)...        8.63574

CORRELATION COEF.......      -0.17476

                 F
               VALUE

               1.54364

                GRAPH CODES

                O=OBSERVED Y
                P=PREDICTED Y
                B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM   -0.4000 TO   19.6000

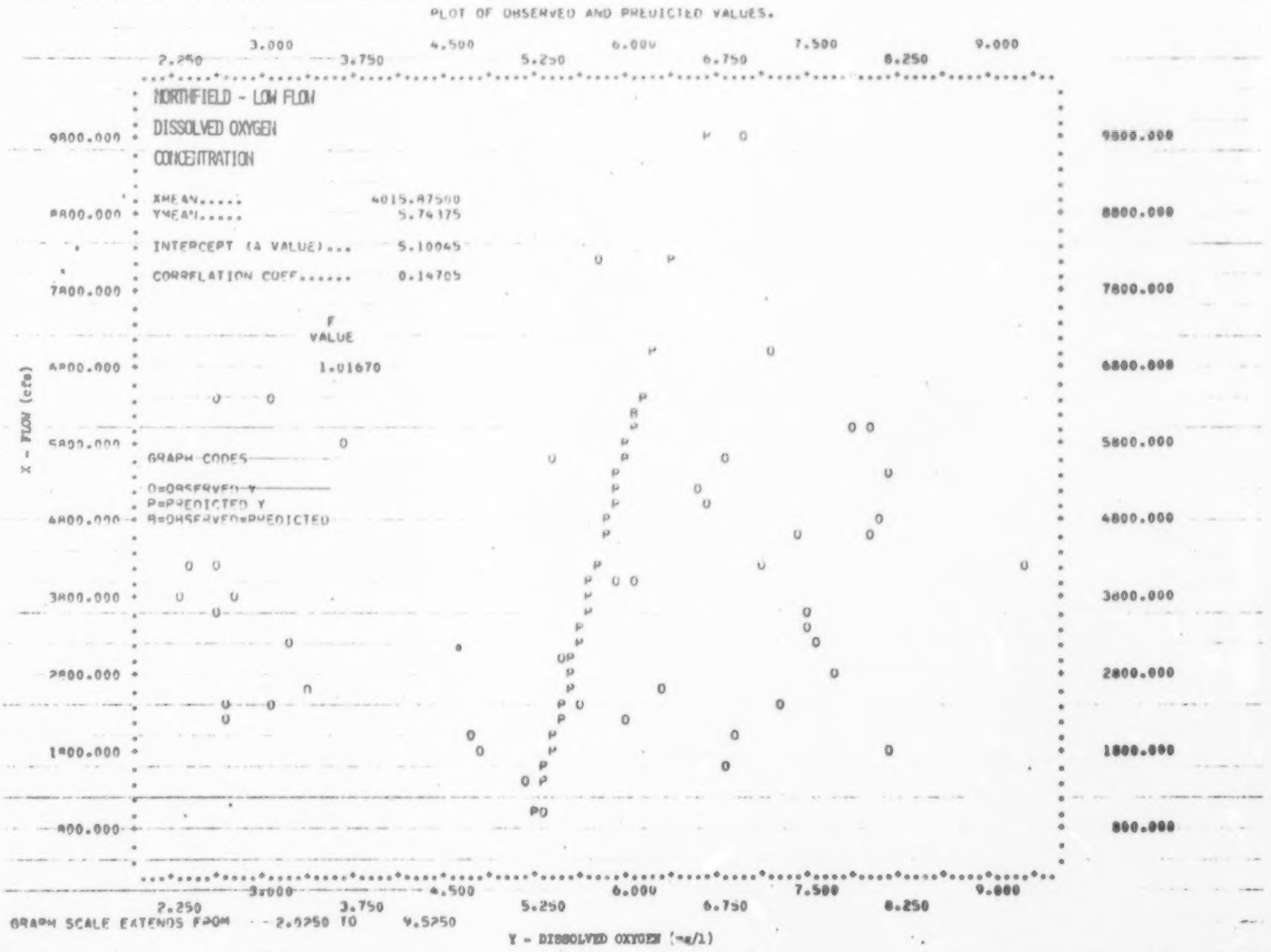
PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - LOW FLOW
TEMPERATURE
16.500
18.000
19.500
21.000
22.500
24.000
25.500
27.000
28.500
30.000
9800.000
8800.000
7800.000
6800.000
5800.000
4800.000
3800.000
2800.000
1800.000
800.000
X - FLOW (cfs)
Y- TEMPERATURE (°C)
XMEAN..... 4015.87500
YMEAN..... 22.42500
INTERCEPT (A VALUE)... 23.14743
CORRELATION COEF...... -0.04908
F VALUE
0.37551
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
GRAPH SCALE EXTENDS FROM 15.1500 TO 30.1500

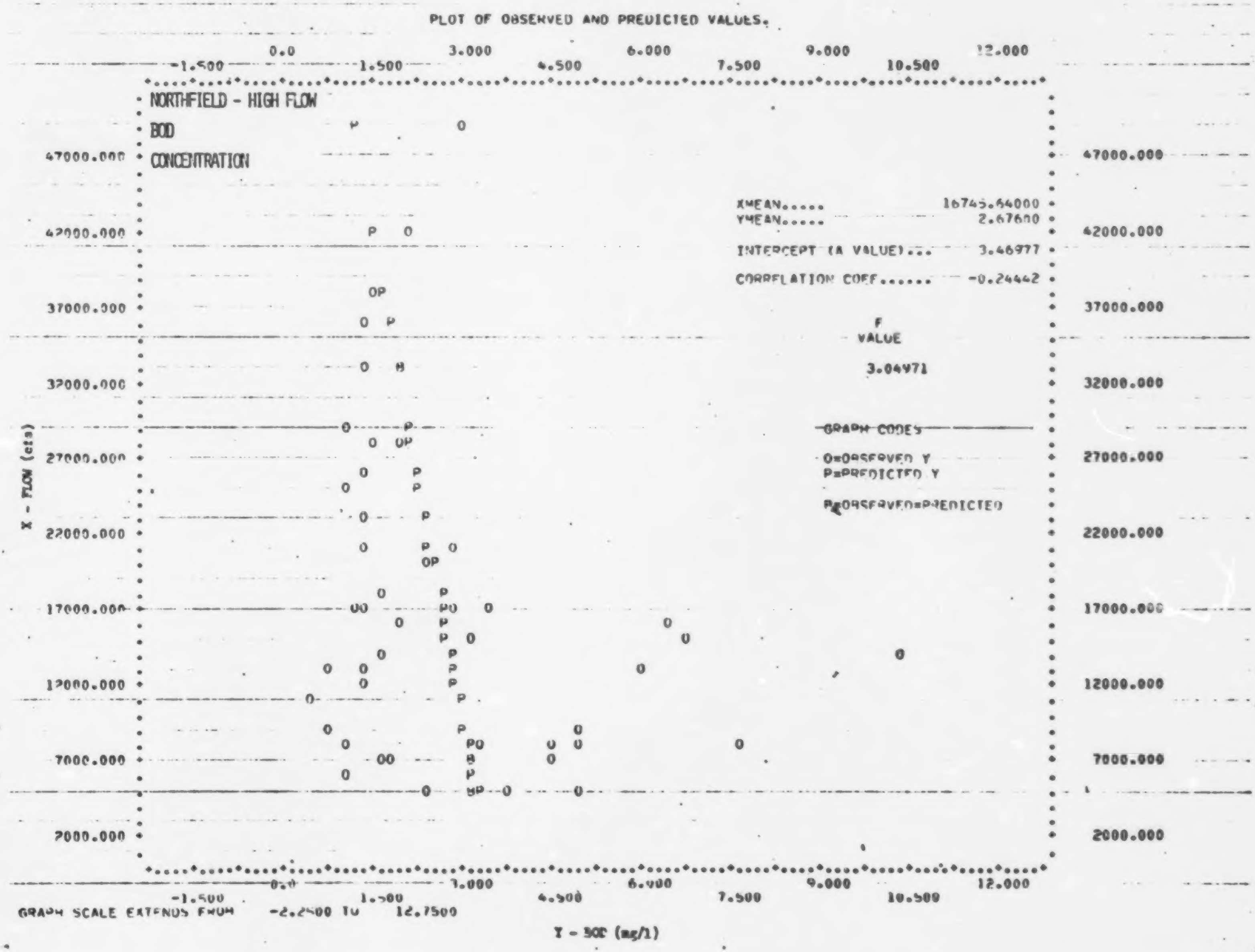
PLOT OF OBSERVED AND PREDICTED VALUES.



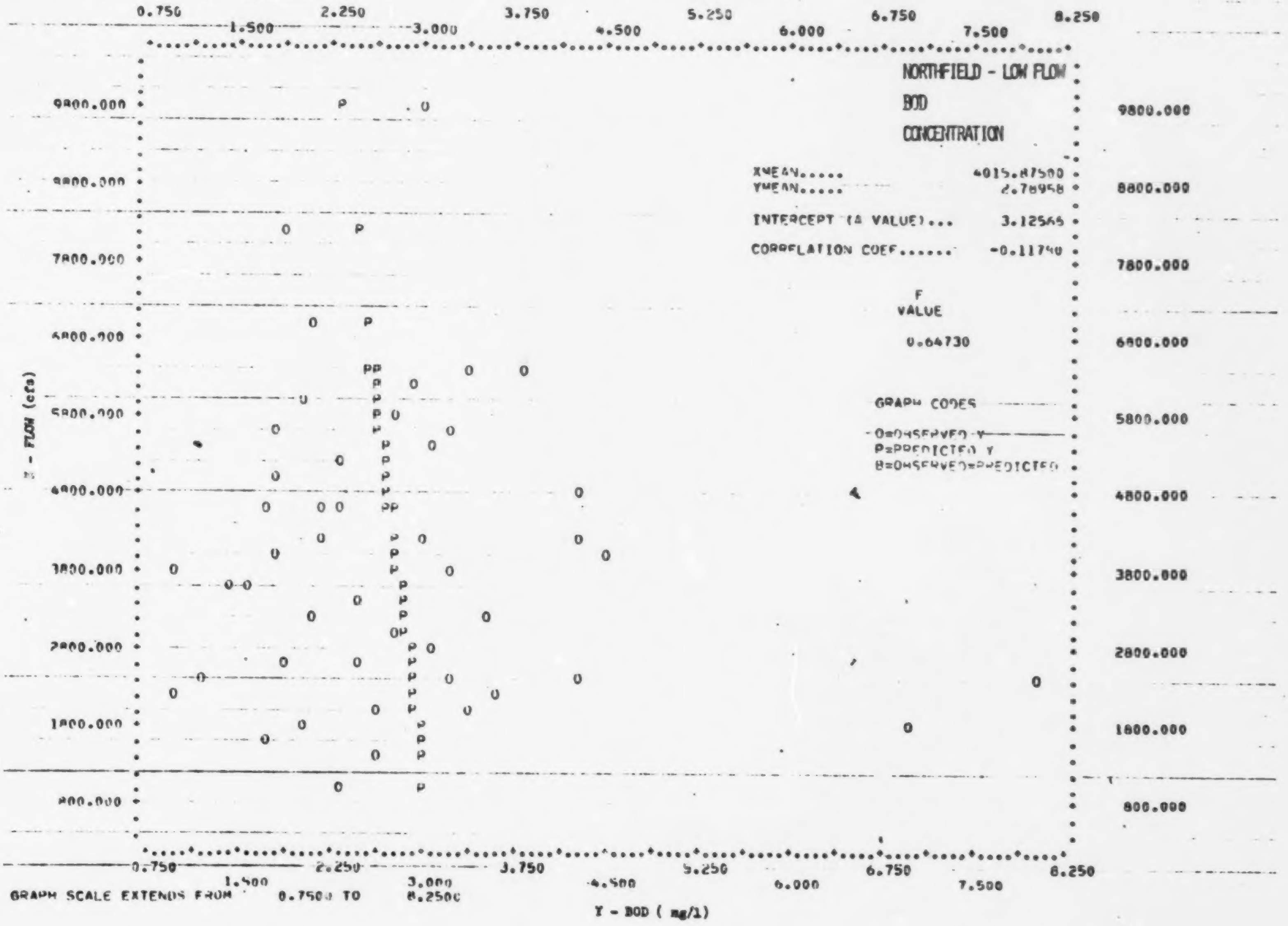
```
XMEAN.....          17741.16981
YMEAN.....             10.32430
INTERCEPT (A VALUE)...  8.81071
CORRELATION COFF.......  0.34194

          F
        VALUE

       6.75250

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

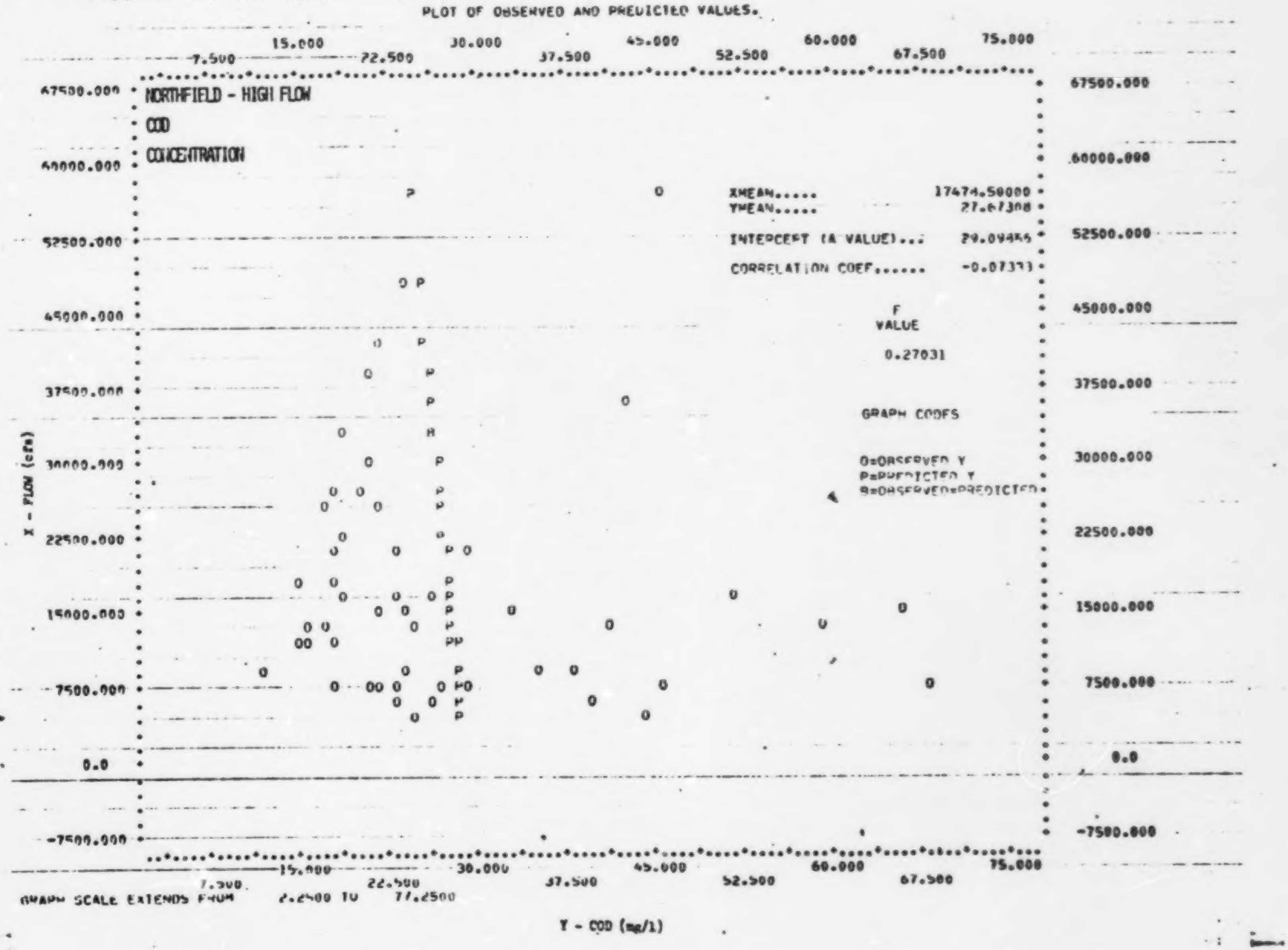
GRAPH SCALE EXTENDS FROM   0.4000 TO   15.9000


PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - LOW FLOW
DISSOLVED OXYGEN
CONCENTRATION
XMEAN..... 4015.87500
YMEAN..... 5.74375
INTERCEPT (A VALUE)... 5.10045
CORRELATION COEF...... 0.14705
F VALUE
1.01670
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
2.250
3.000
3.750
4.500
5.250
6.000
6.750
7.500
8.250
9.000
9800.000
8800.000
7800.000
6800.000
5800.000
4800.000
3800.000
2800.000
1800.000
800.000
X - FLOW (cfs)
Y - DISSOLVED OXYGEN (mg/l)
GRAPH SCALE EXTENDS FROM 2.0250 TO 9.5250


PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - HIGH FLOW
BOD
CONCENTRATION
XMEAN..... 16745.64000
YMEAN..... 2.67600
INTERCEPT (A VALUE)... 3.46977
CORRELATION COEF...... -0.24442
F VALUE
3.04971
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
-1.500
0.0
1.500
3.000
4.500
6.000
7.500
9.000
10.500
12.000
47000.000
42000.000
37000.000
32000.000
27000.000
22000.000
17000.000
12000.000
7000.000
2000.000
X - FLOW (cfs)
GRAPH SCALE EXTENDS FROM -2.2500 TO 12.7500
Y - BOD (mg/l)

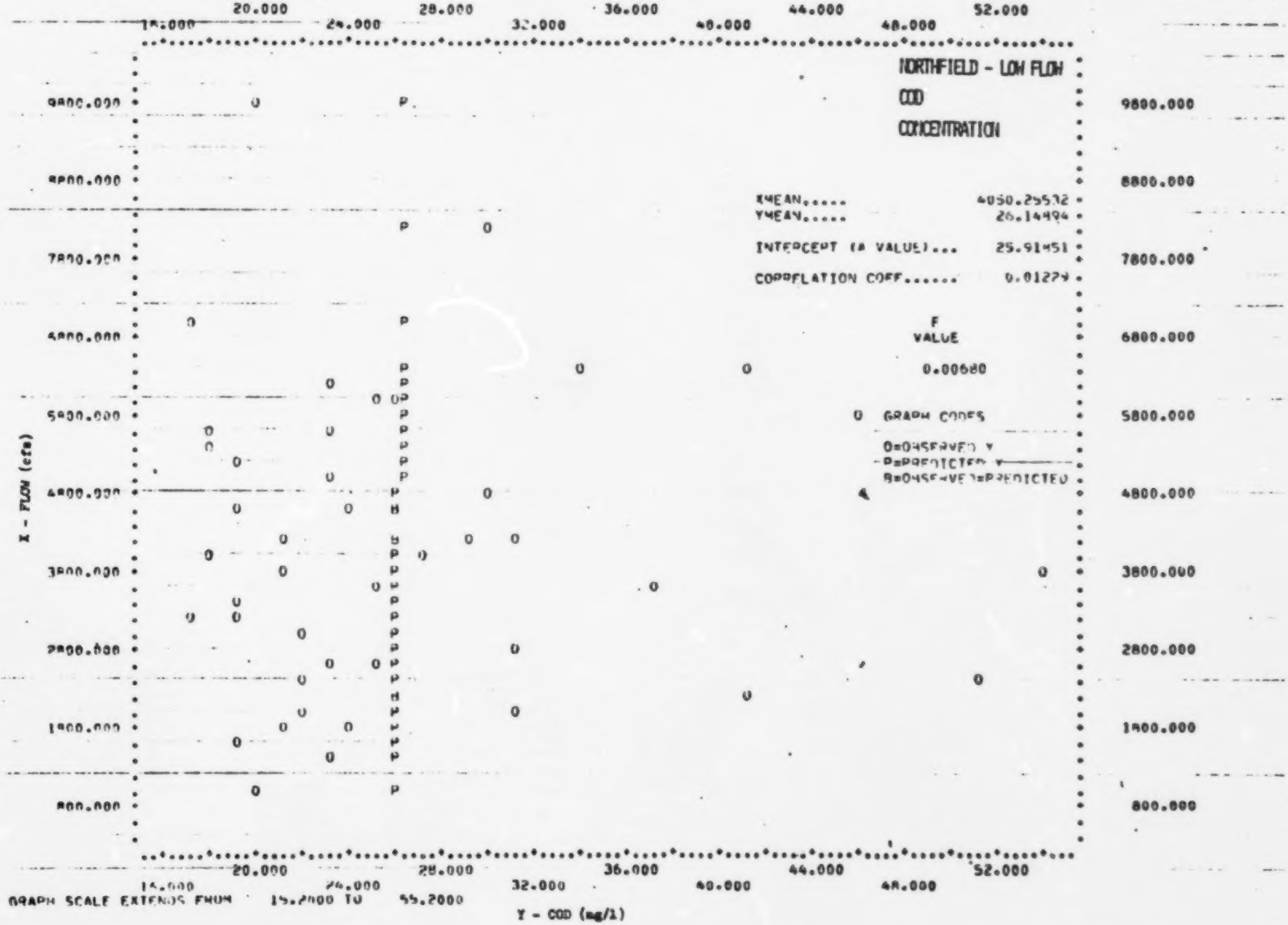
PLOT OF OBSERVED AND PREDICTED VALUES.





PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - HIGH FLOW
COD
CONCENTRATION
XMEAN..... 17474.50000
YMEAN..... 27.67308
INTERCEPT (A VALUE)... 29.09455
CORRELATION COEF...... -0.07333
F VALUE
0.27031
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
X - FLOW (cfs)
Y - COD (mg/l)
67500.000
60000.000
52500.000
45000.000
37500.000
30000.000
22500.000
15000.000
7500.000
0.0
-7500.000
7.500
15.000
22.500
30.000
37.500
45.000
52.500
60.000
67.500
75.000
GRAPH SCALE EXTENDS FROM 2.2500 TO 77.2500

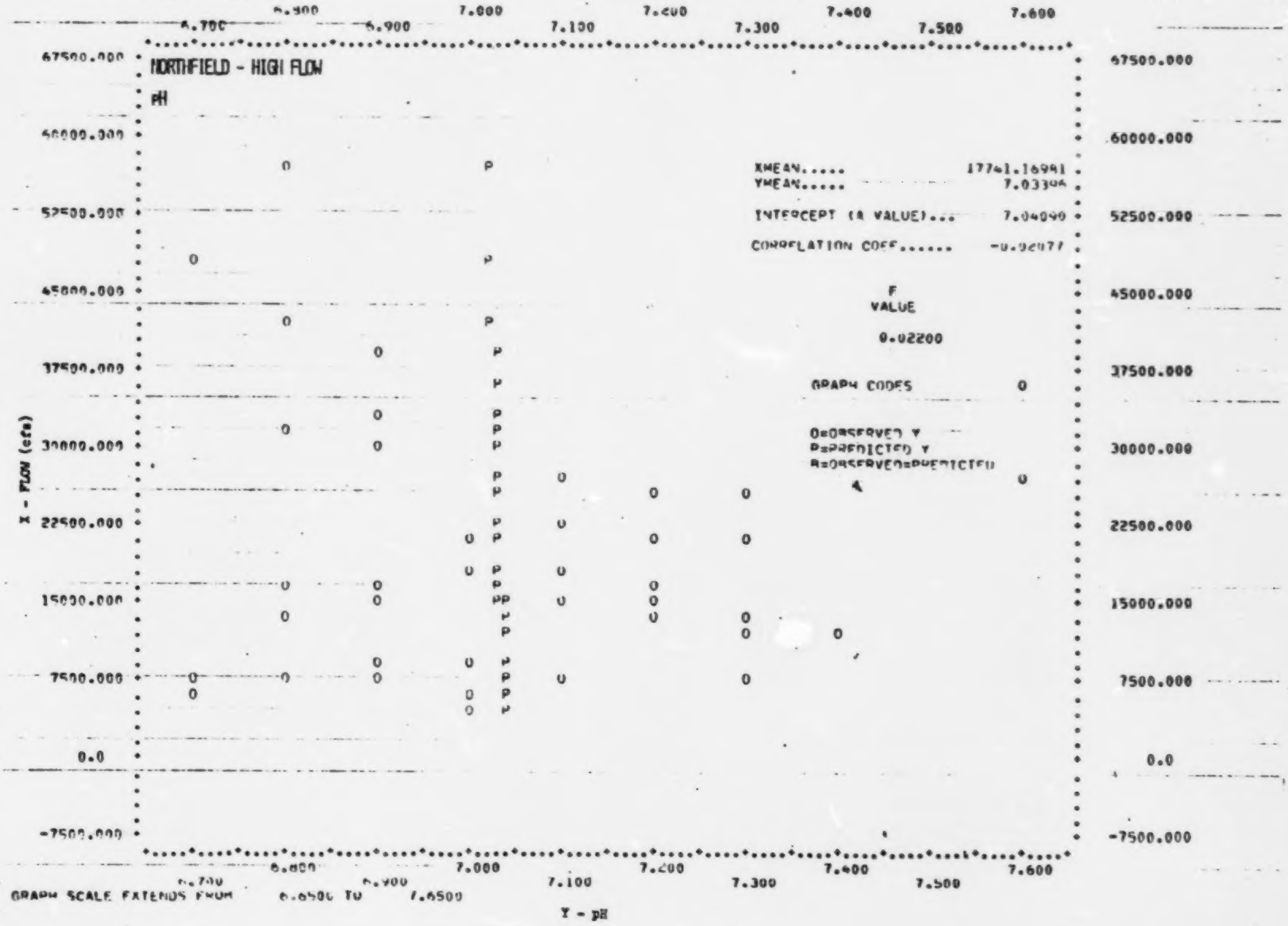
PLOT OF OBSERVED AND PREDICTED VALUES.



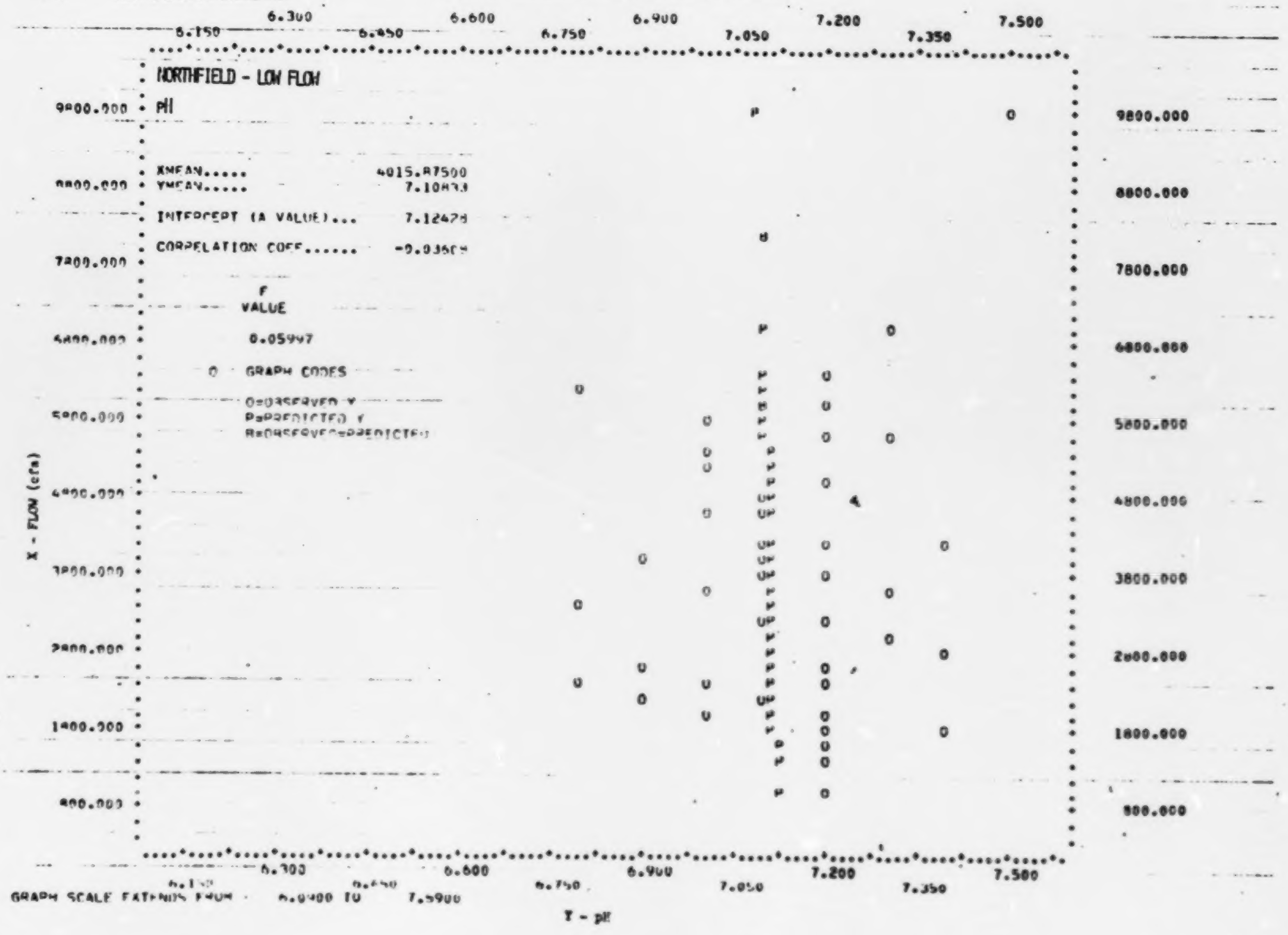
```
XMEAN.....                 4050.25532
YMEAN.....                   26.14494

INTERCEPT (A VALUE)...       25.91451

CORRELATION COEFF......       0.01229

                    F
                  VALUE
                 0.00680
```

GRAPH SCALE EXTENDS FROM   15.2000 TO   55.2000

PLOT OF OBSERVED AND P[illegible]DICTED VALUES.



PLOT OF OBSERVED AND PREDICTED VALUES.



NORTHFIELD - LOW FLOW

pH

XMEAN..... 4015.87500
YMEAN..... 7.10833

INTERCEPT (A VALUE)... 7.12478

CORRELATION COEFF...... -0.03509

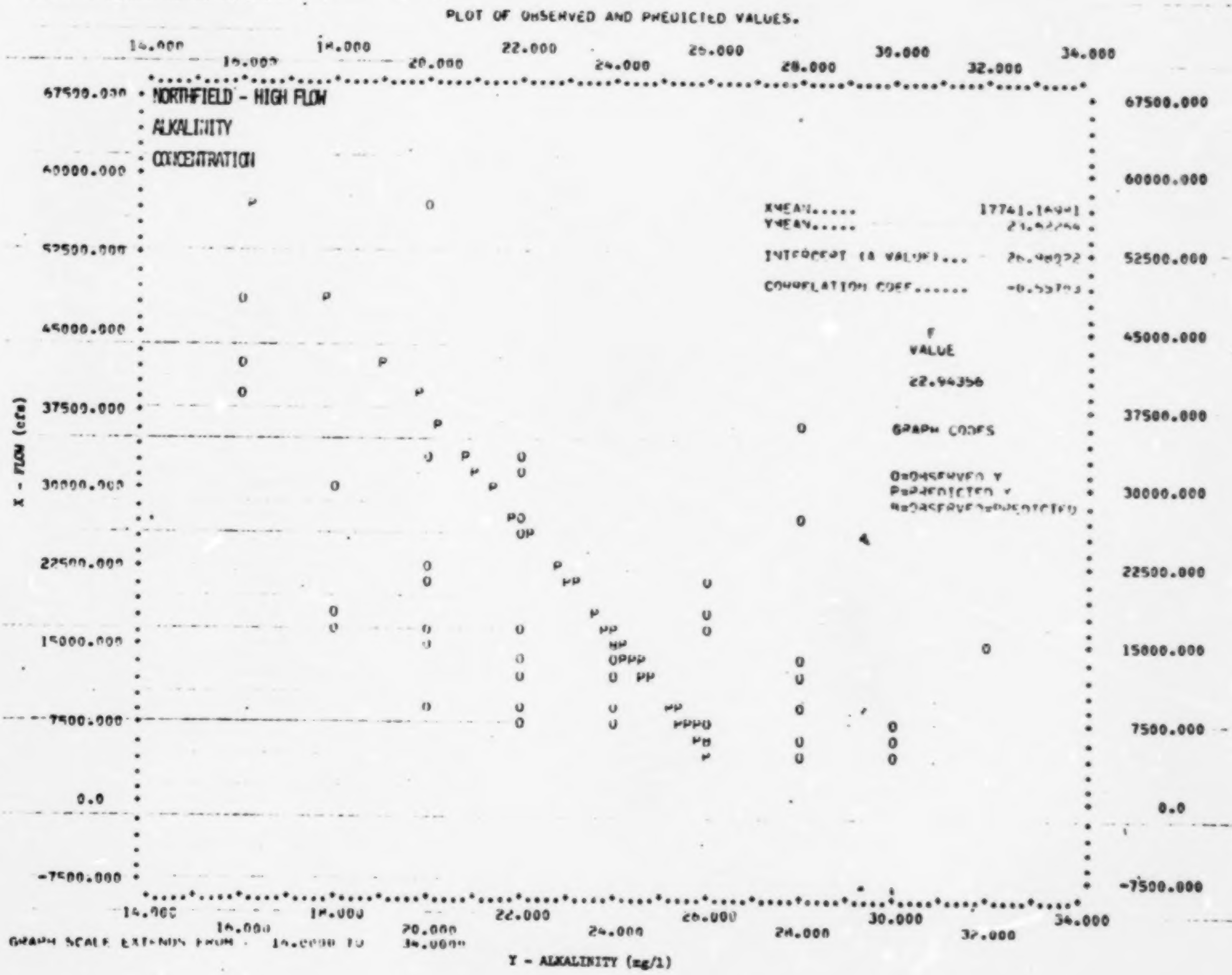
F VALUE

0.05947

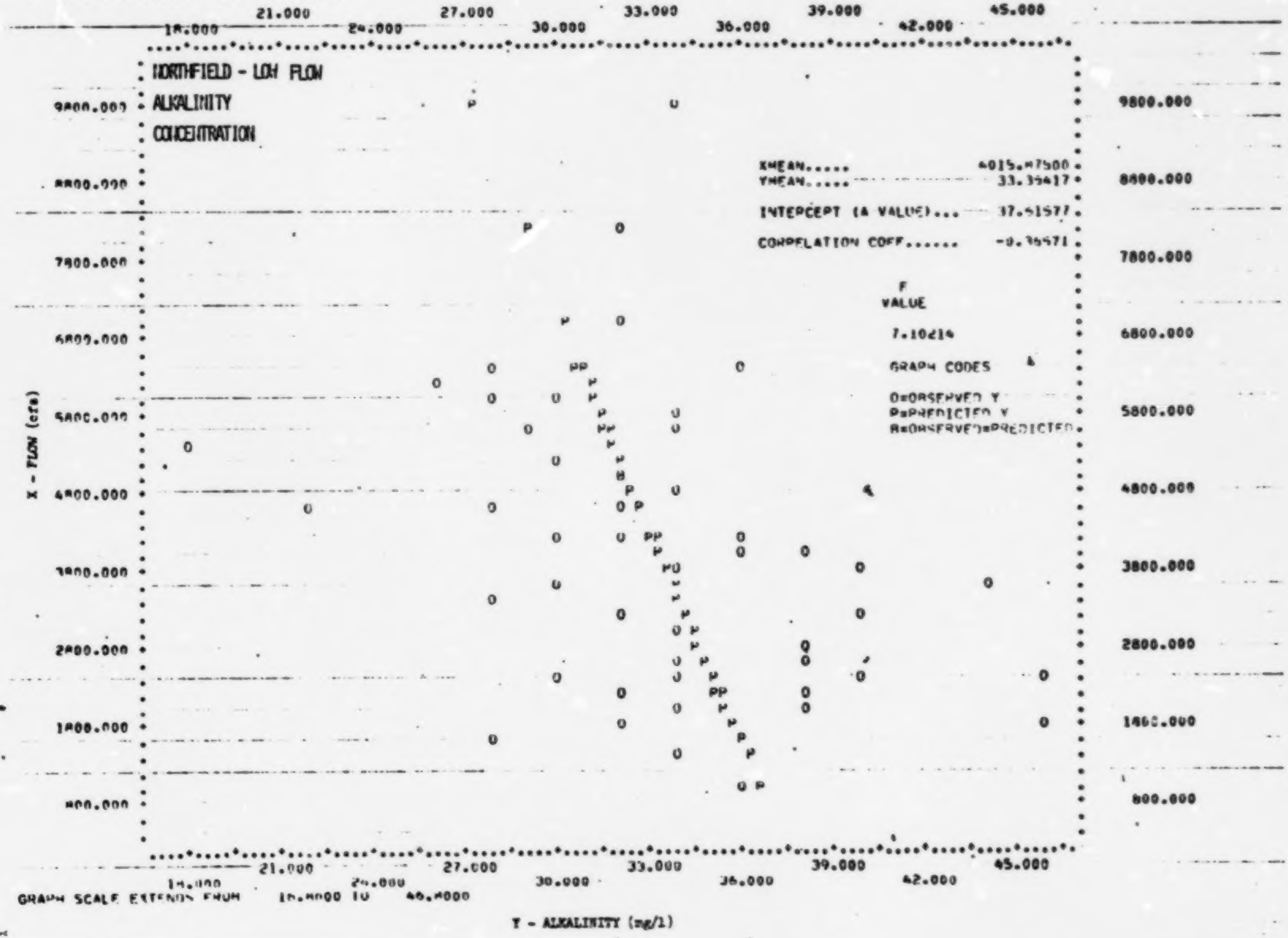
0 GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

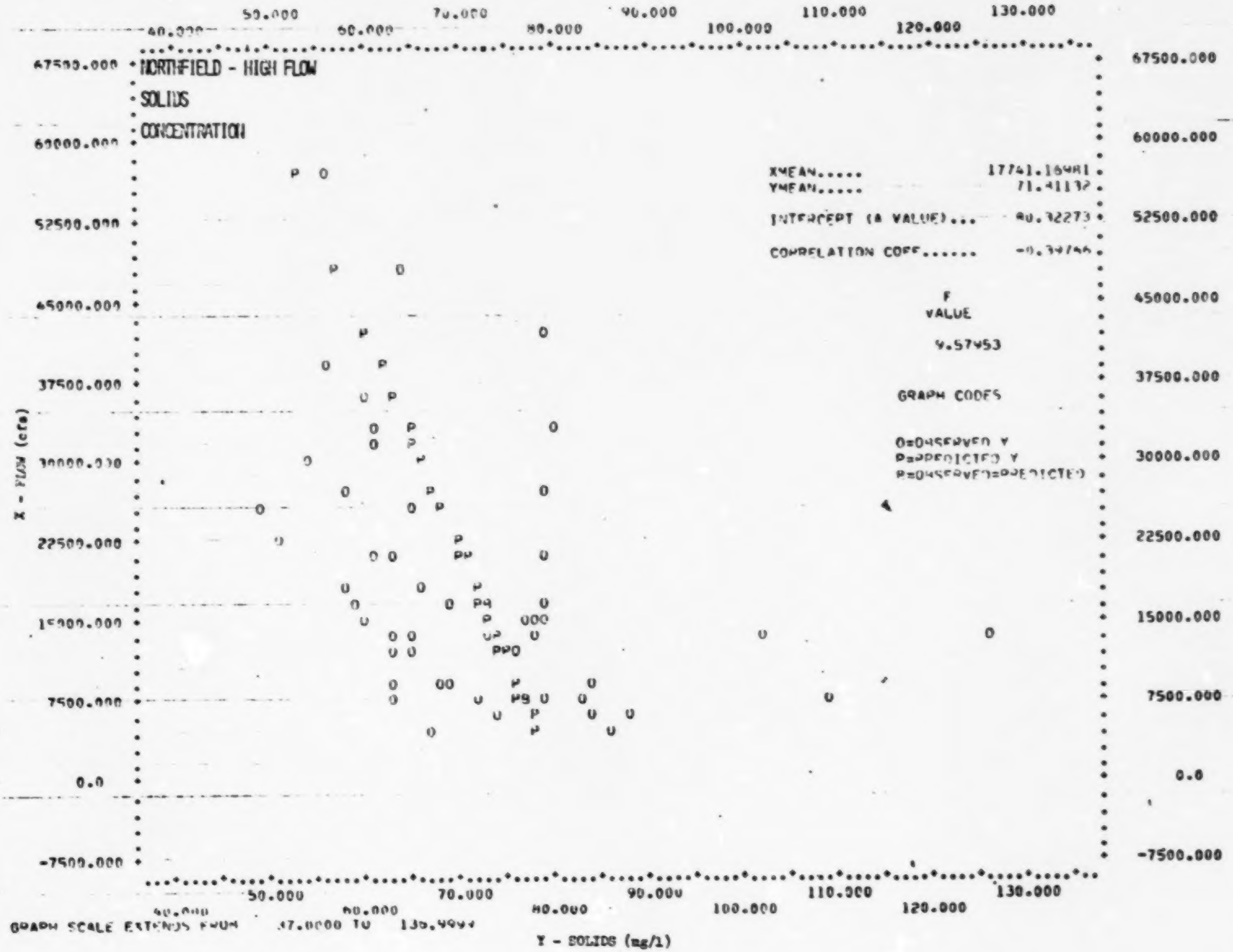
GRAPH SCALE EXTENDS FROM 6.0900 TO 7.5900

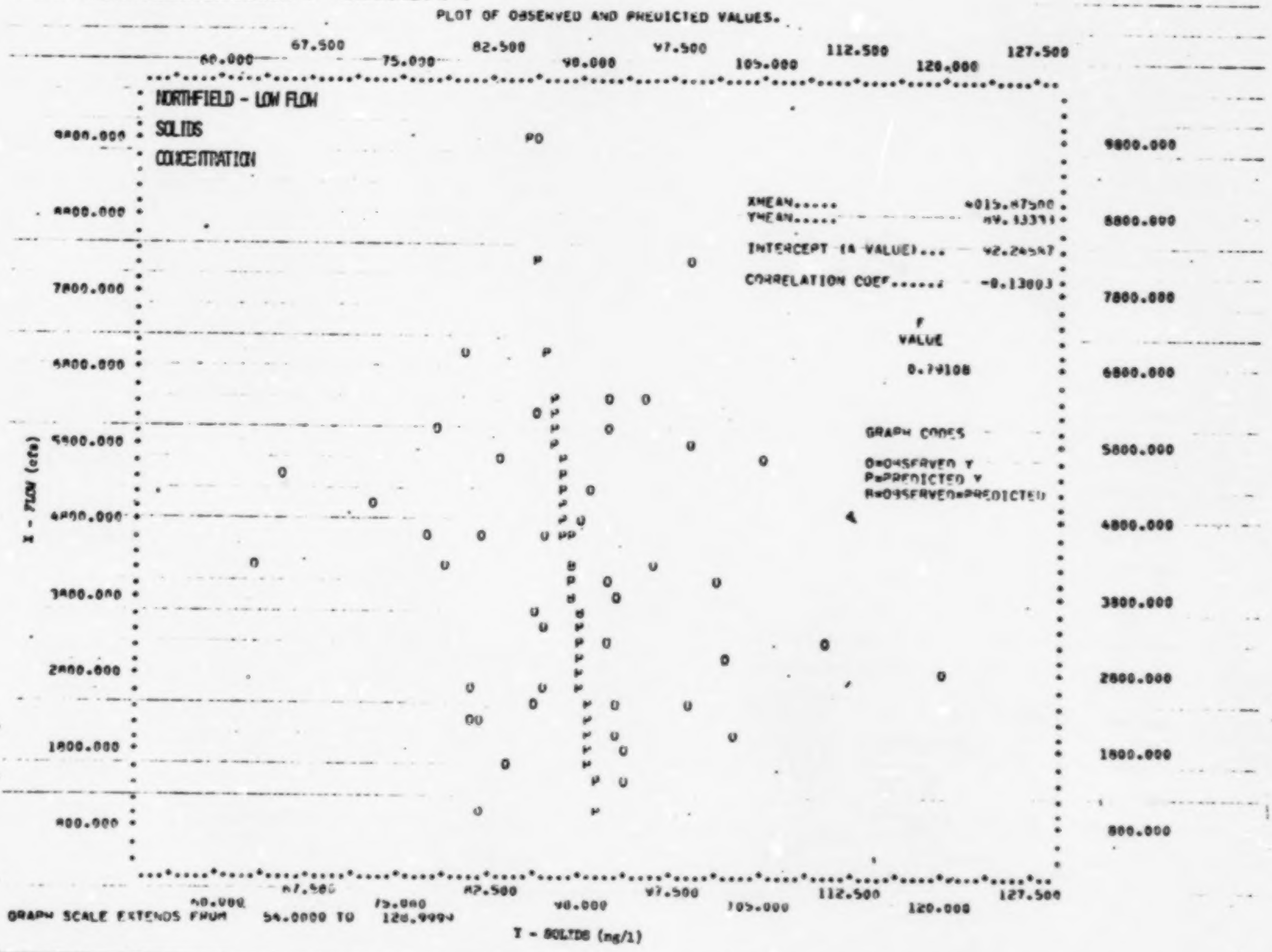

PLOT OF OBSERVED AND PREDICTED VALUES.
14.000
16.000
18.000
20.000
22.000
24.000
26.000
28.000
30.000
32.000
34.000
67500.000
60000.000
52500.000
45000.000
37500.000
30000.000
22500.000
15000.000
7500.000
0.0
-7500.000
NORTHFIELD - HIGH FLOW
ALKALINITY
CONCENTRATION
XMEAN..... 17741.14441
YMEAN..... 21.62266
INTERCEPT (A VALUE)... 26.46922
CORRELATION COEF....... -0.55703
F
VALUE
22.94356
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
X - FLOW (cfs)
Y - ALKALINITY (mg/1)
GRAPH SCALE EXTENDS FROM 14.0000 TO 34.0000

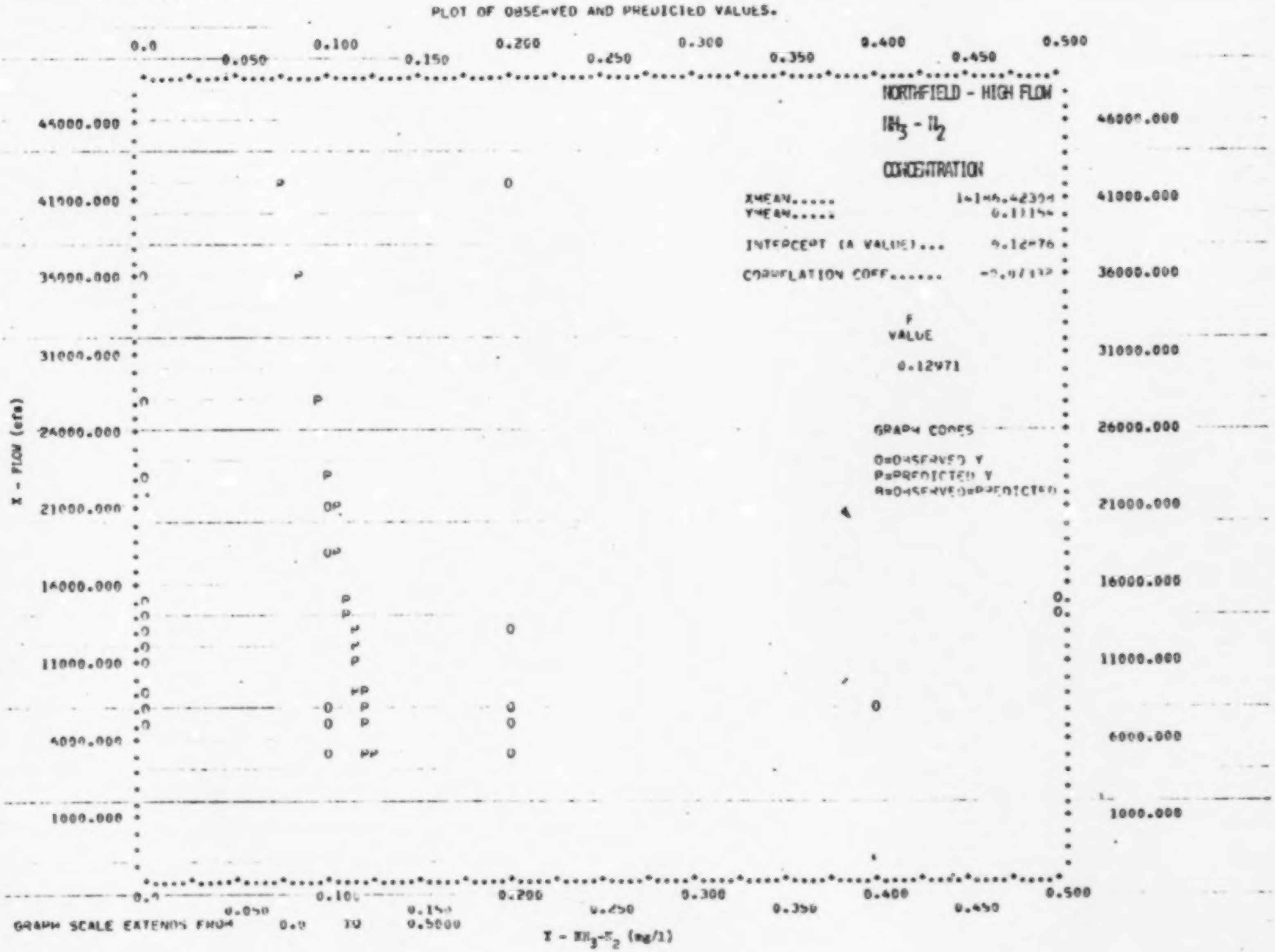
PLOT OF OBSERVED AND PREDICTED VALUES.



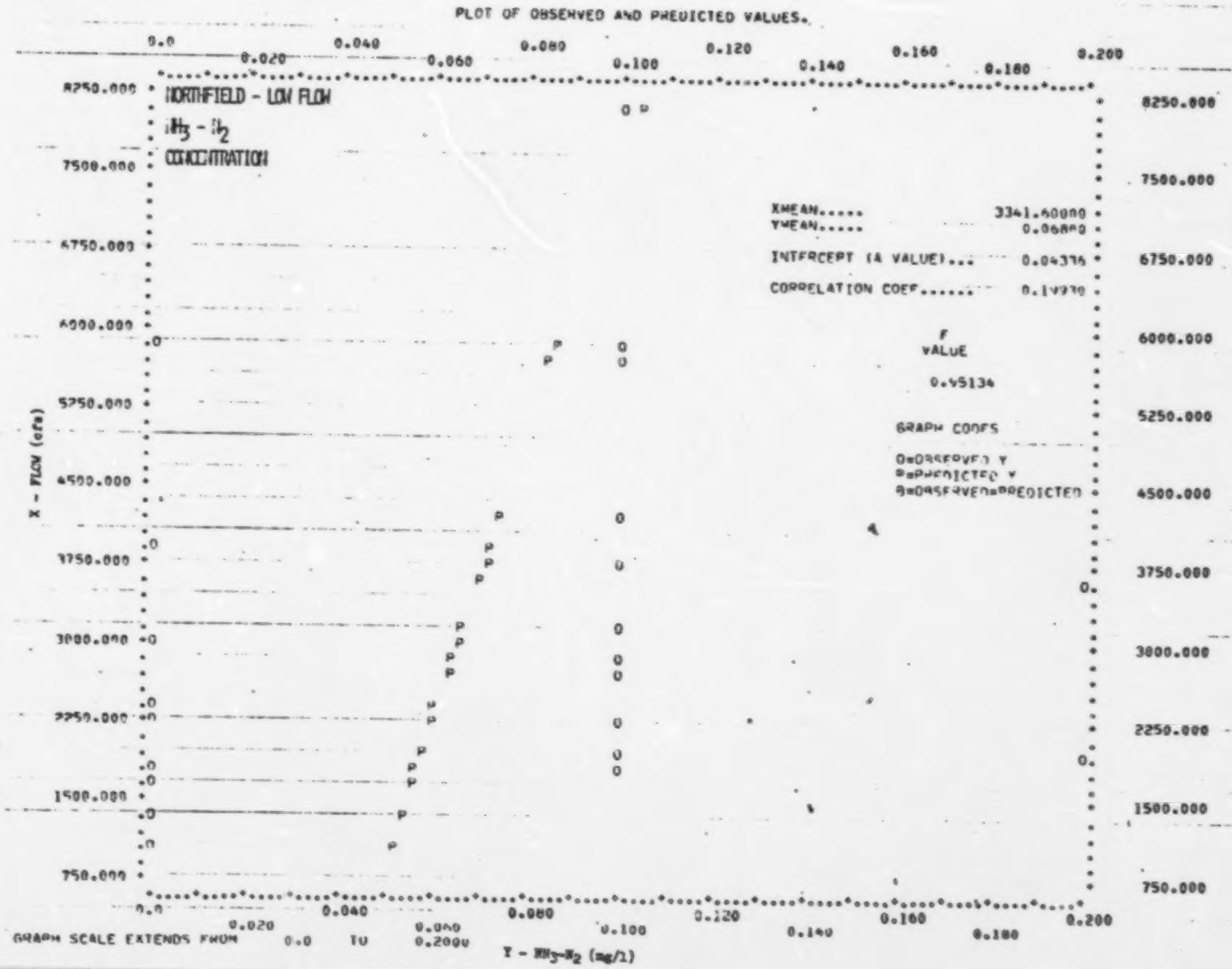
PLOT OF OBSERVED AND PREDICTED VALUES.




PLOT OF OBSERVED AND PREDICTED VALUES.
60.000
67.500
75.000
82.500
90.000
97.500
105.000
112.500
120.000
127.500
NORTHFIELD - LOW FLOW
SOLIDS
CONCENTRATION
9800.000
8800.000
7800.000
6800.000
5800.000
4800.000
3800.000
2800.000
1800.000
800.000
XMEAN..... 4015.87500
YMEAN..... 89.13333
INTERCEPT (A VALUE)... 92.24587
CORRELATION COEF...... -0.13803
F
VALUE
0.79108
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
X - FLOW (cfs)
GRAPH SCALE EXTENDS FROM 54.0000 TO 128.9999
Y - SOLIDS (mg/l)


PLOT OF OBSERVED AND PREDICTED VALUES.
0.0
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400
0.450
0.500
NORTHFIELD - HIGH FLOW
$NH_3 - N_2$
CONCENTRATION
XMEAN..... 14146.42394
YMEAN..... 0.11156
INTERCEPT (A VALUE)... 0.12876
CORRELATION COEF...... -0.07132
F VALUE
0.12971
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
46000.000
41000.000
36000.000
31000.000
26000.000
21000.000
16000.000
11000.000
6000.000
1000.000
X - FLOW (cfs)
GRAPH SCALE EXTENDS FROM 0.0 TO 0.5000
Y - NH_3-N_2 (mg/l)

PLOT OF OBSERVED AND PREDICTED VALUES.

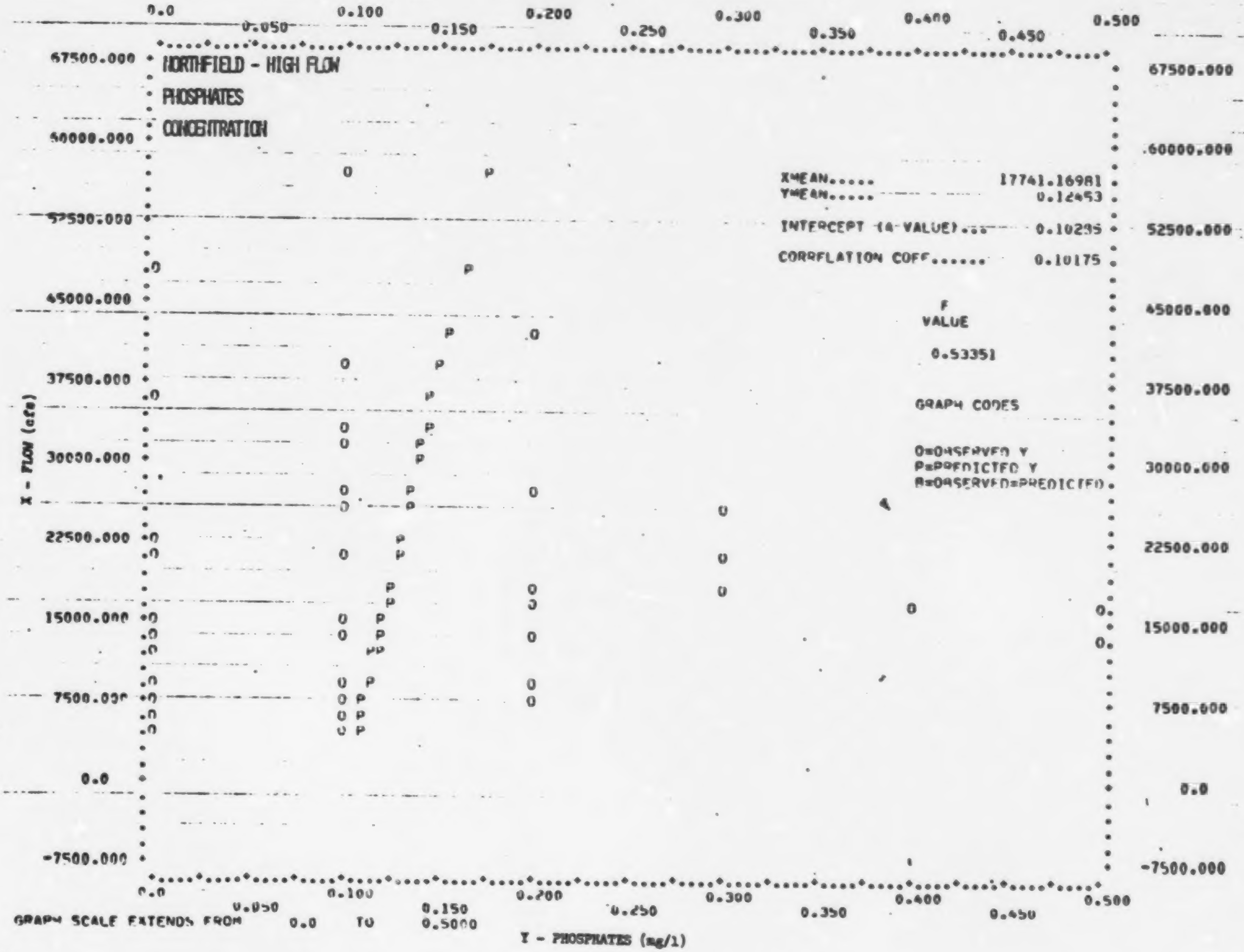


XMEAN..... 3341.60000
YMEAN..... 0.06880
INTERCEPT (A VALUE)... 0.04336
CORRELATION COEF...... 0.14930

F VALUE
0.45134

GRAPH SCALE EXTENDS FROM 0.0 TO 0.2000

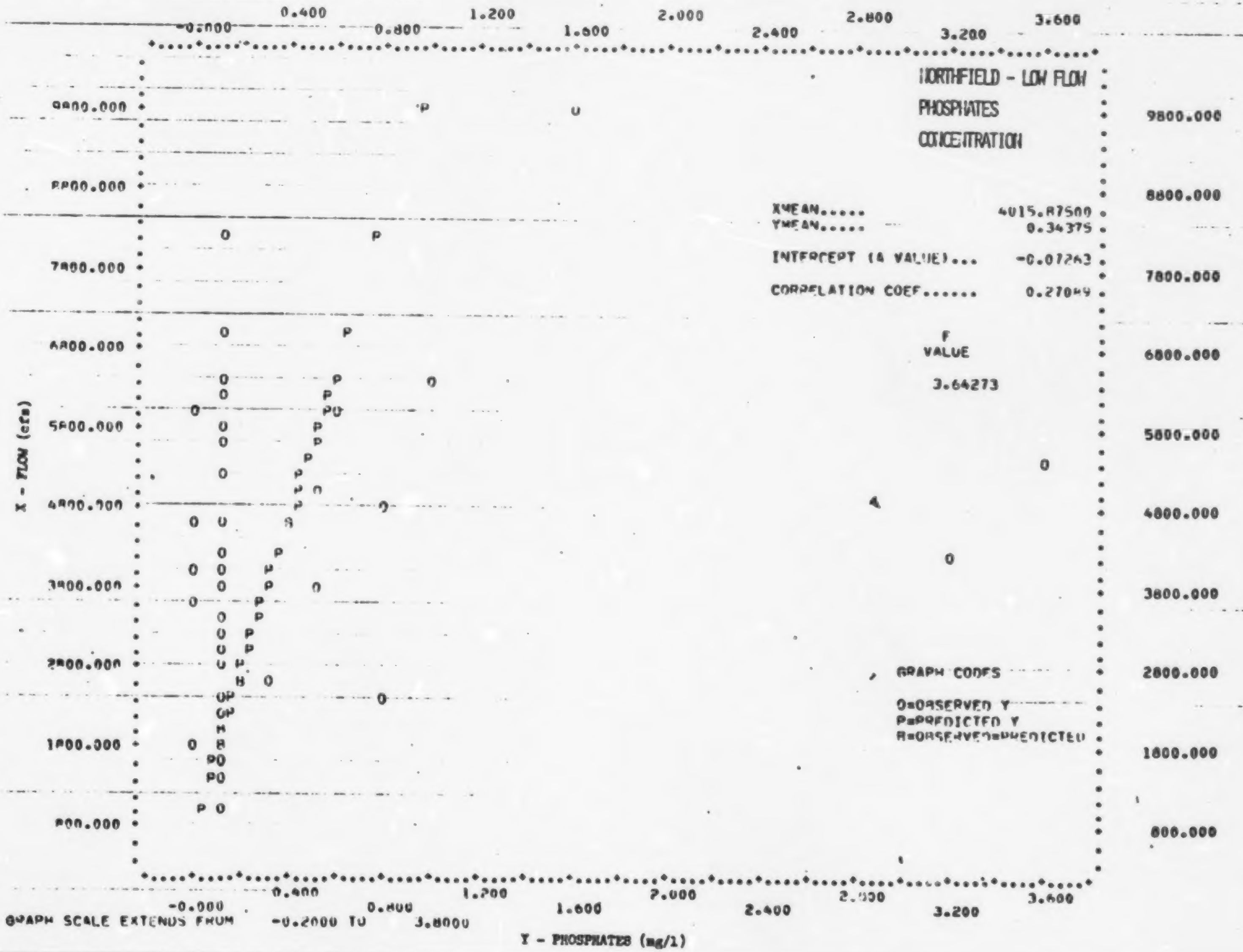
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                17741.16981
YMEAN.....                    0.12453
INTERCEPT (A VALUE)...        0.10295
CORRELATION COFF......        0.10175

             F
           VALUE
           0.53351

         GRAPH CODES

         O=OBSERVED Y
         P=PREDICTED Y
         B=OBSERVED=PREDICTED
```

```
GRAPH SCALE EXTENDS FROM    0.0    TO    0.5000
```

PLOT OF OBSERVED AND PREDICTED VALUES.

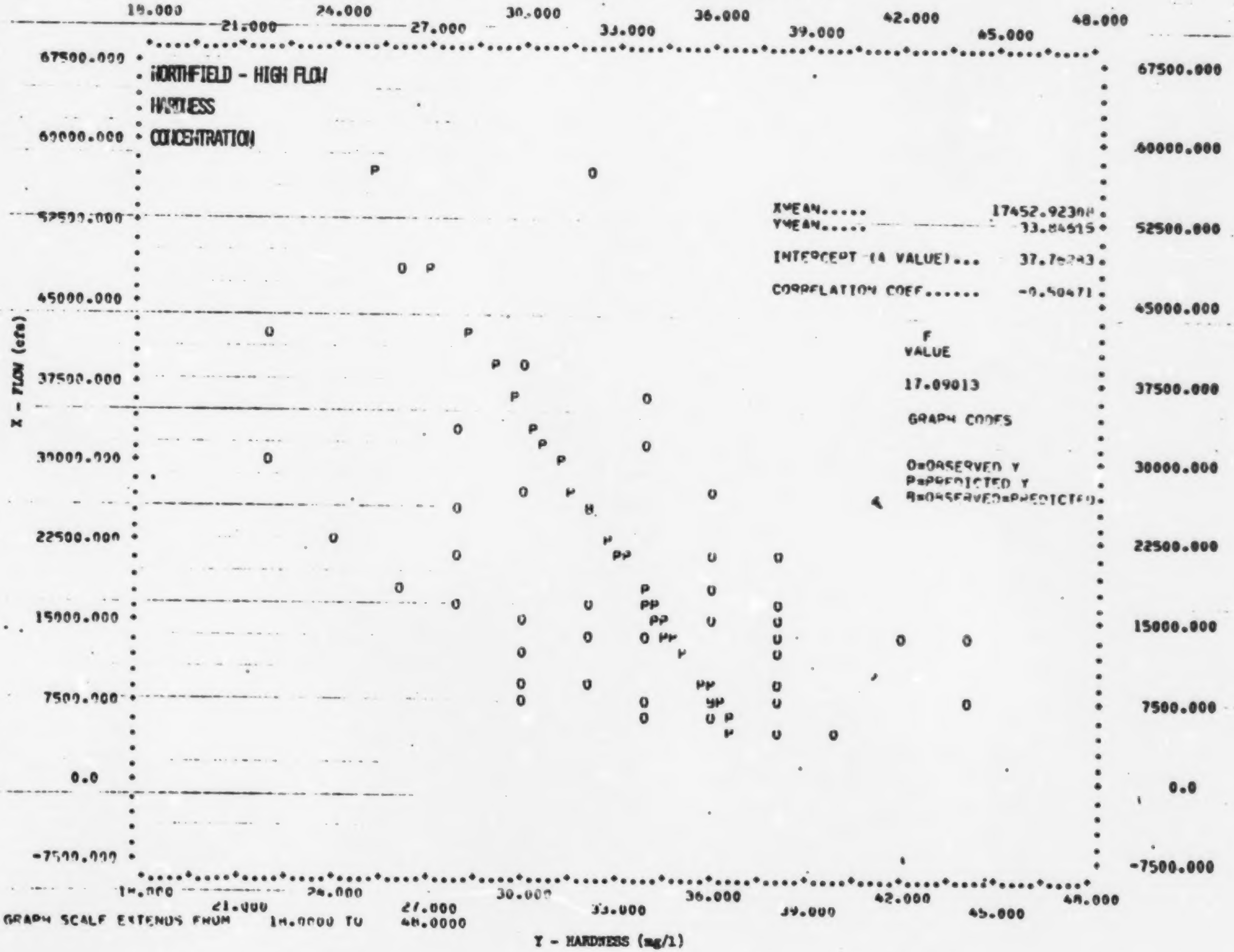


NORTHFIELD - LOW FLOW
PHOSPHATES
CONCENTRATION

```
XMEAN.....                4015.87500
YMEAN.....                   0.34375
INTERCEPT (A VALUE)...      -0.07263
CORRELATION COEF......       0.27049

     F
   VALUE
  3.64273

GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM -0.2000 TO 3.8000

PLOT OF OBSERVED AND PREDICTED VALUES.



XMEAN..... 17452.92308
YMEAN..... 33.84615

INTERCEPT (A VALUE)... 37.76243

CORRELATION COEF....... -0.50471

F
VALUE

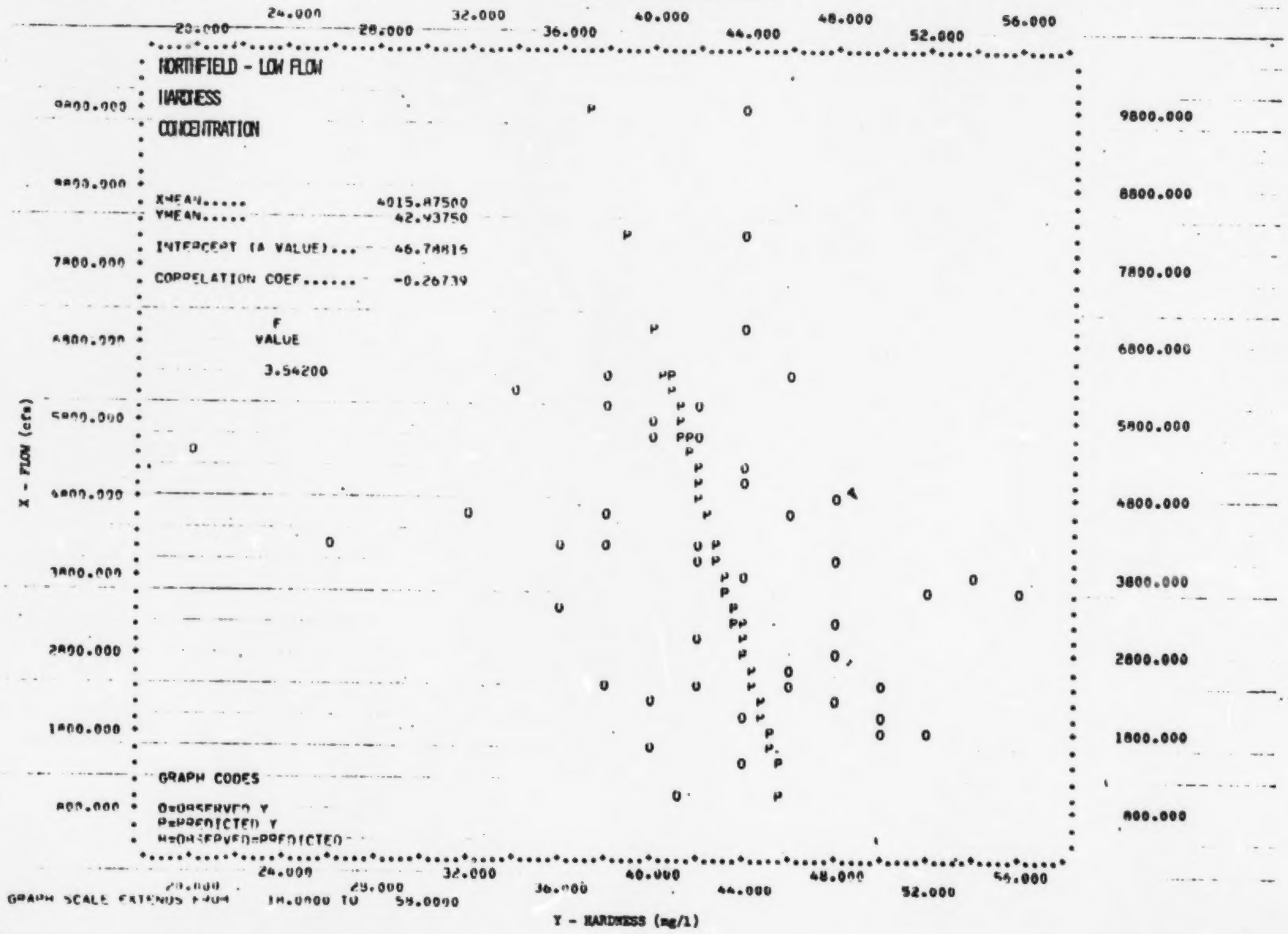
17.09013

GRAPH CODES

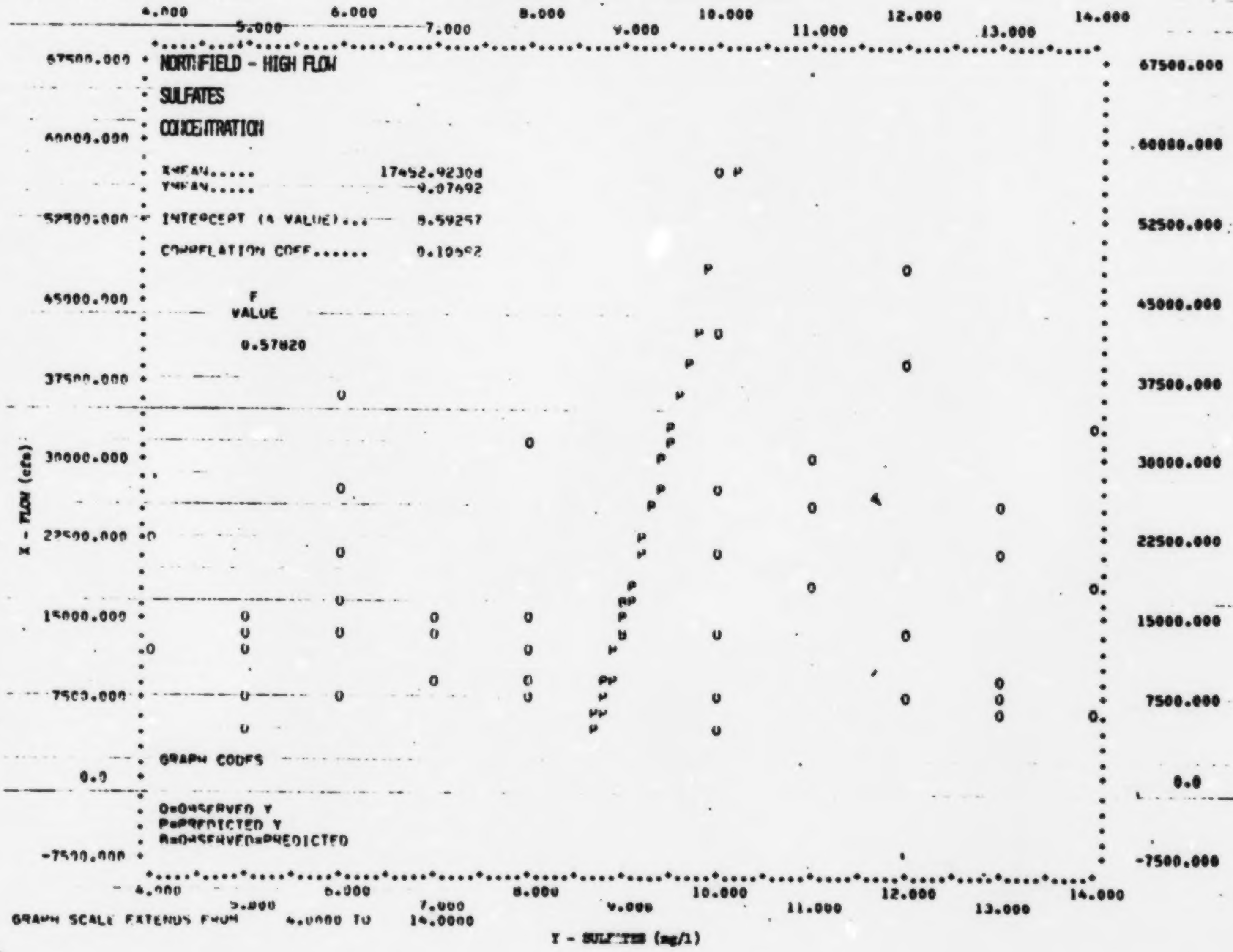
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM 18.0000 TO 48.0000

PLOT OF OBSERVED AND PREDICTED VALUES.

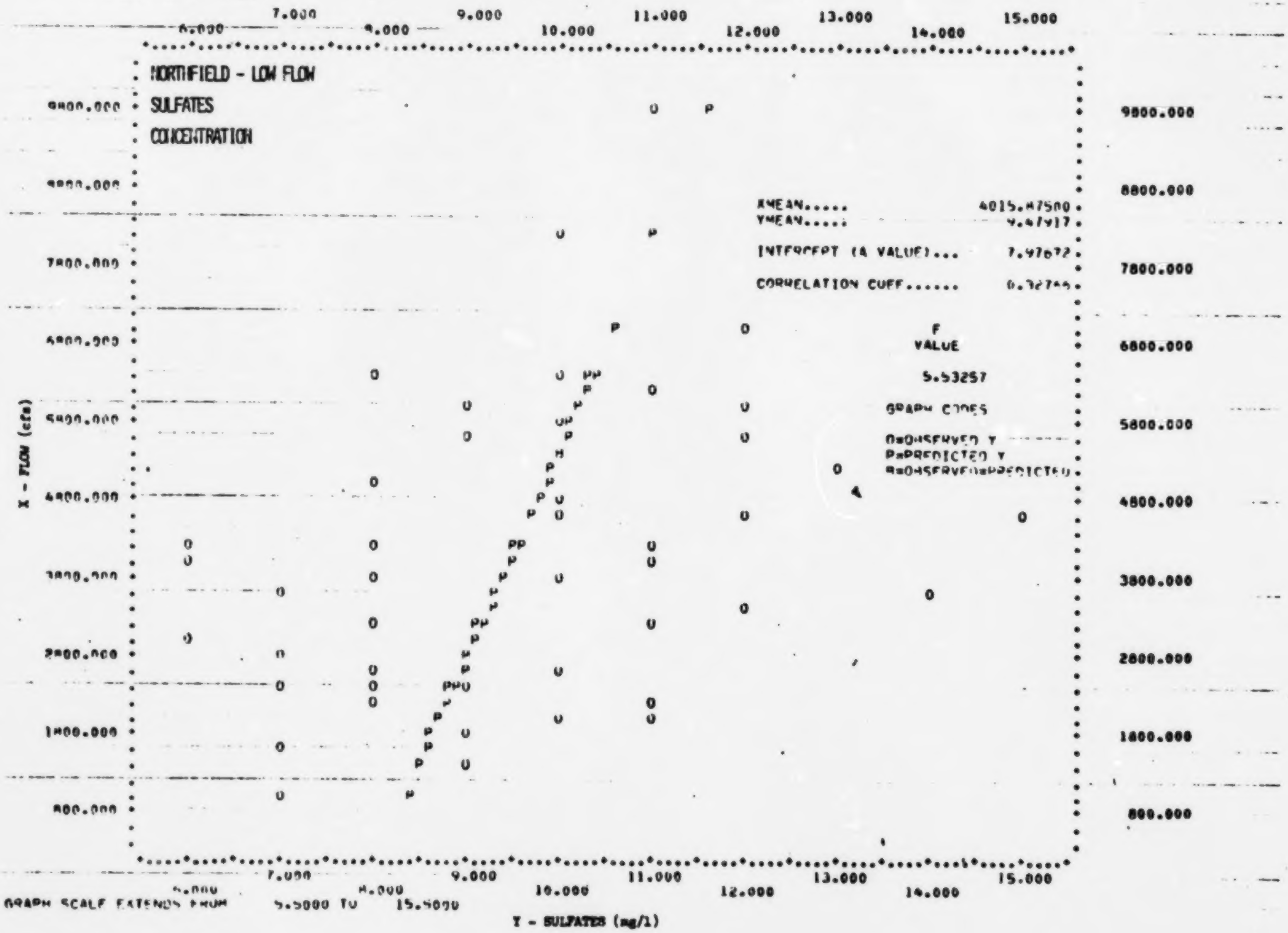


PLOT OF OBSERVED AND PREDICTED VALUES.

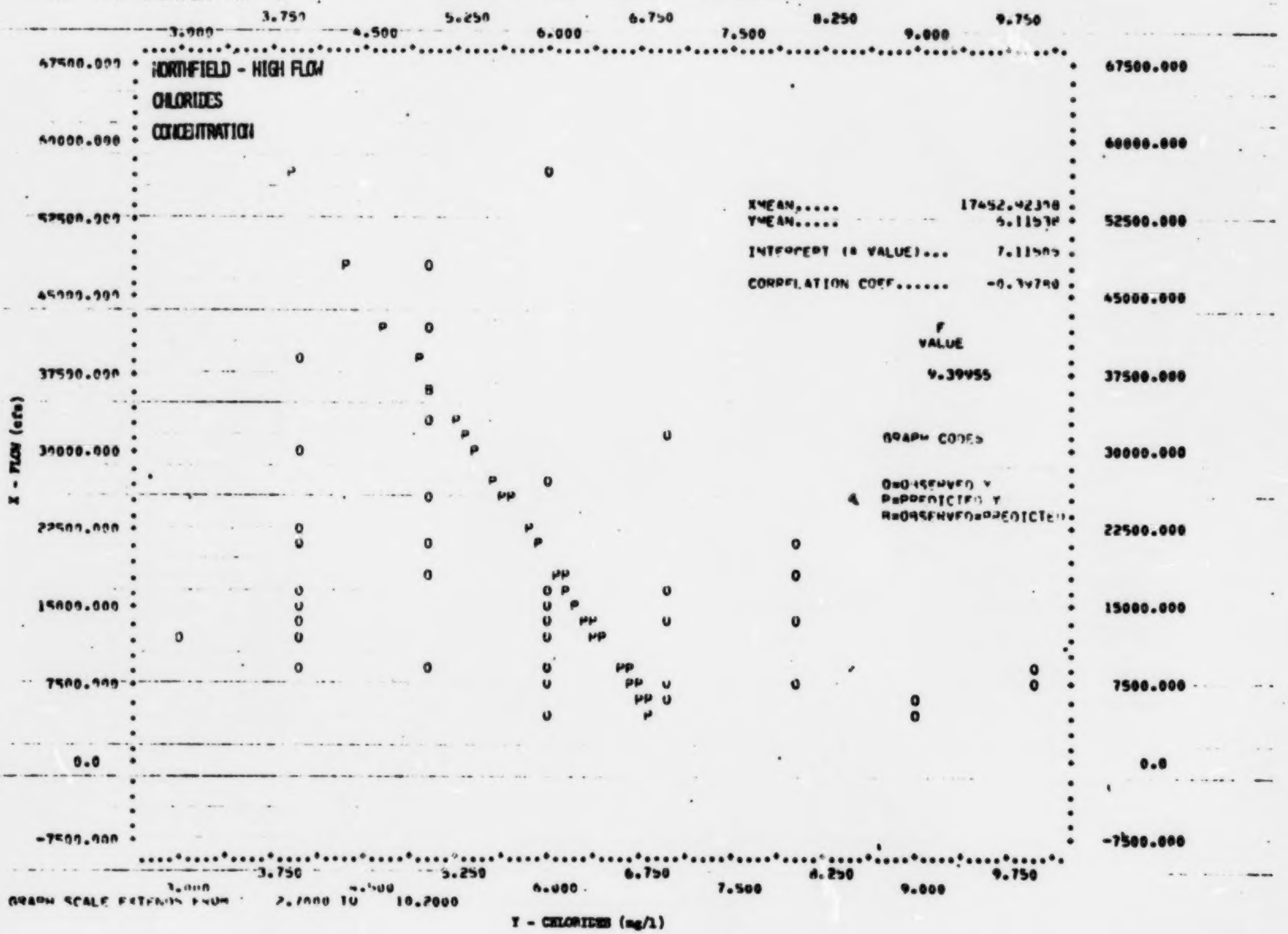


GRAPH SCALE EXTENDS FROM 4.0000 TO 14.0000

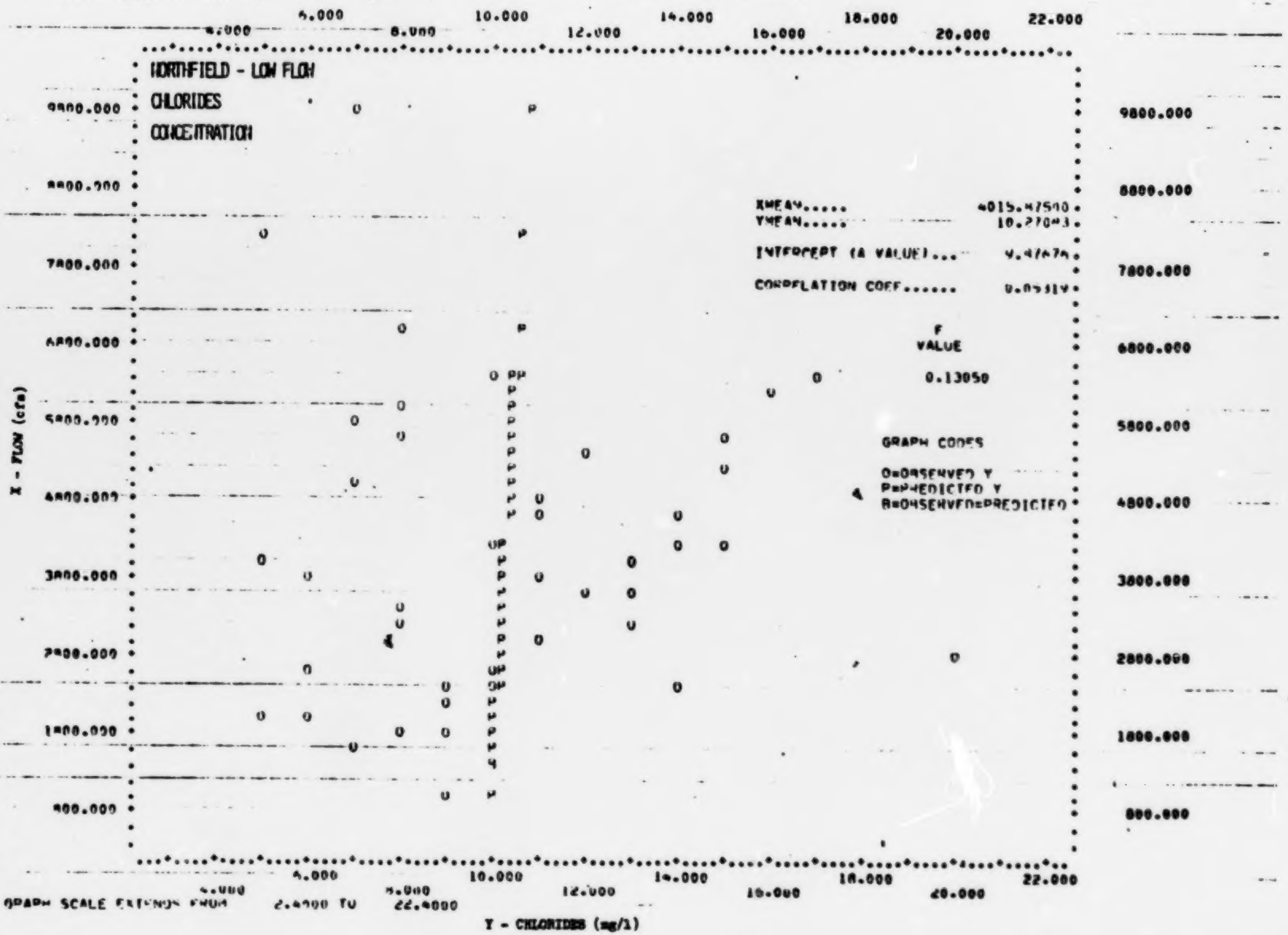
PLOT OF OBSERVED AND PREDICTED VALUES.



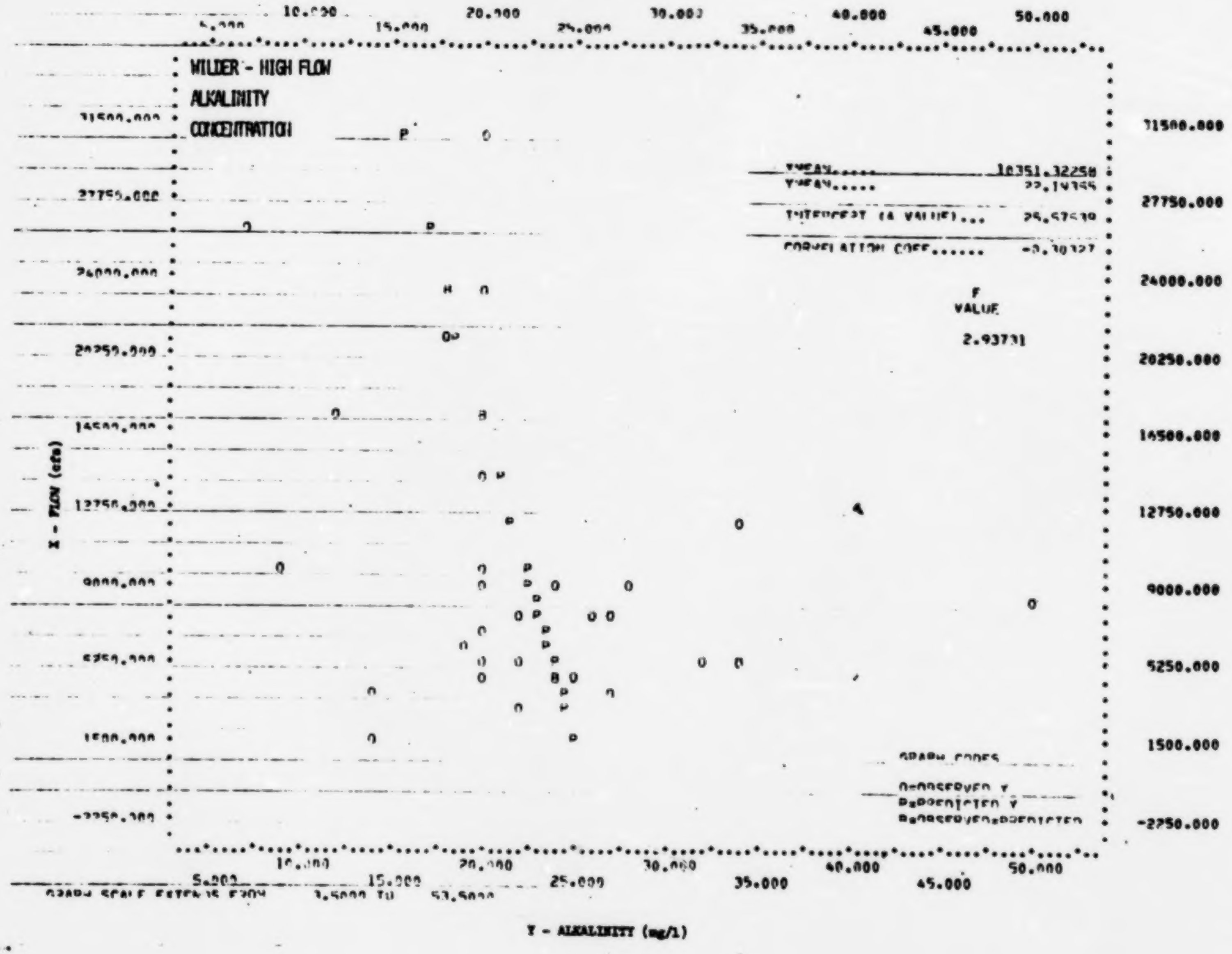
PLOT OF OBSERVED AND PREDICTED VALUES.



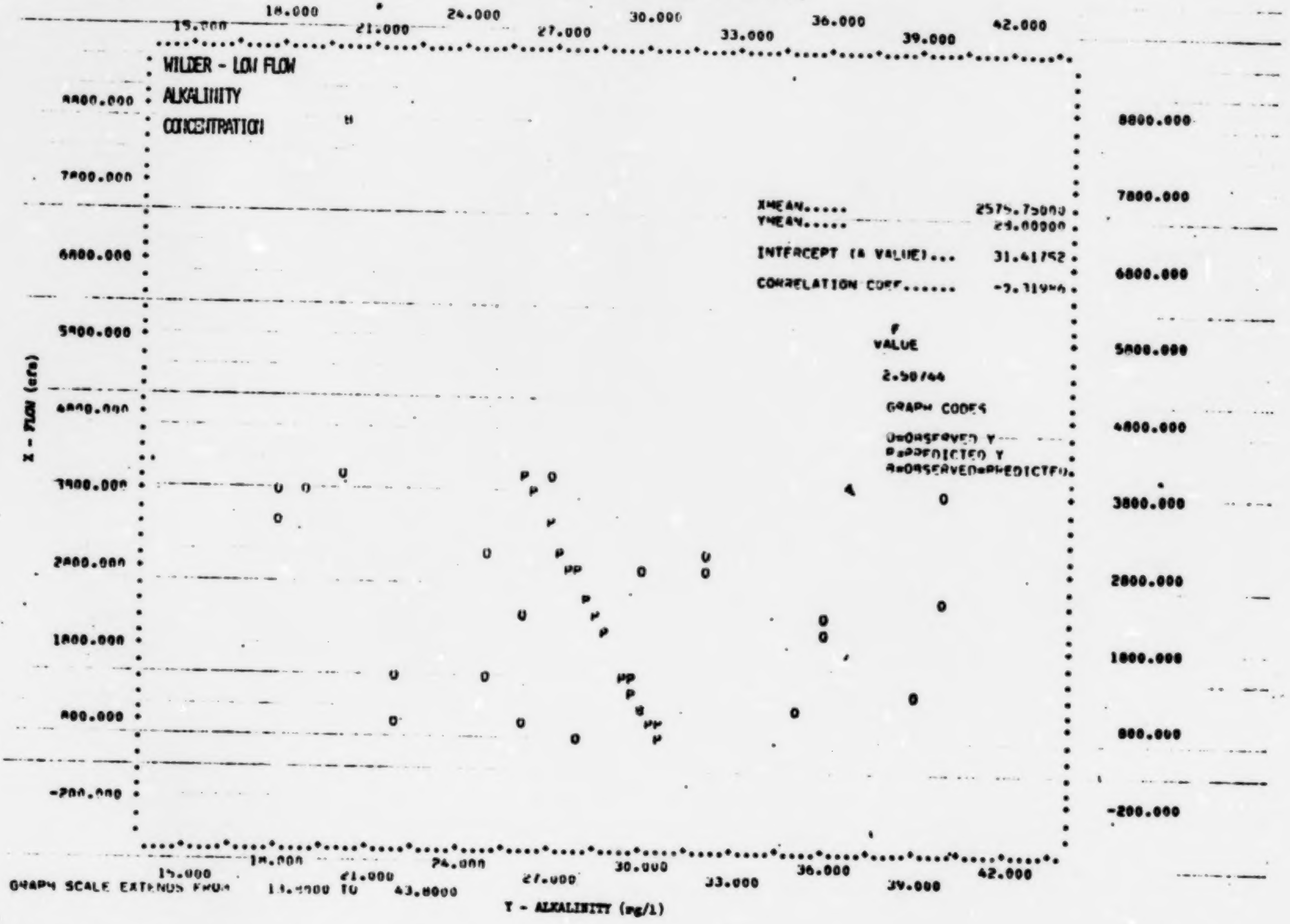
PLOT OF OBSERVED AND PREDICTED VALUES.



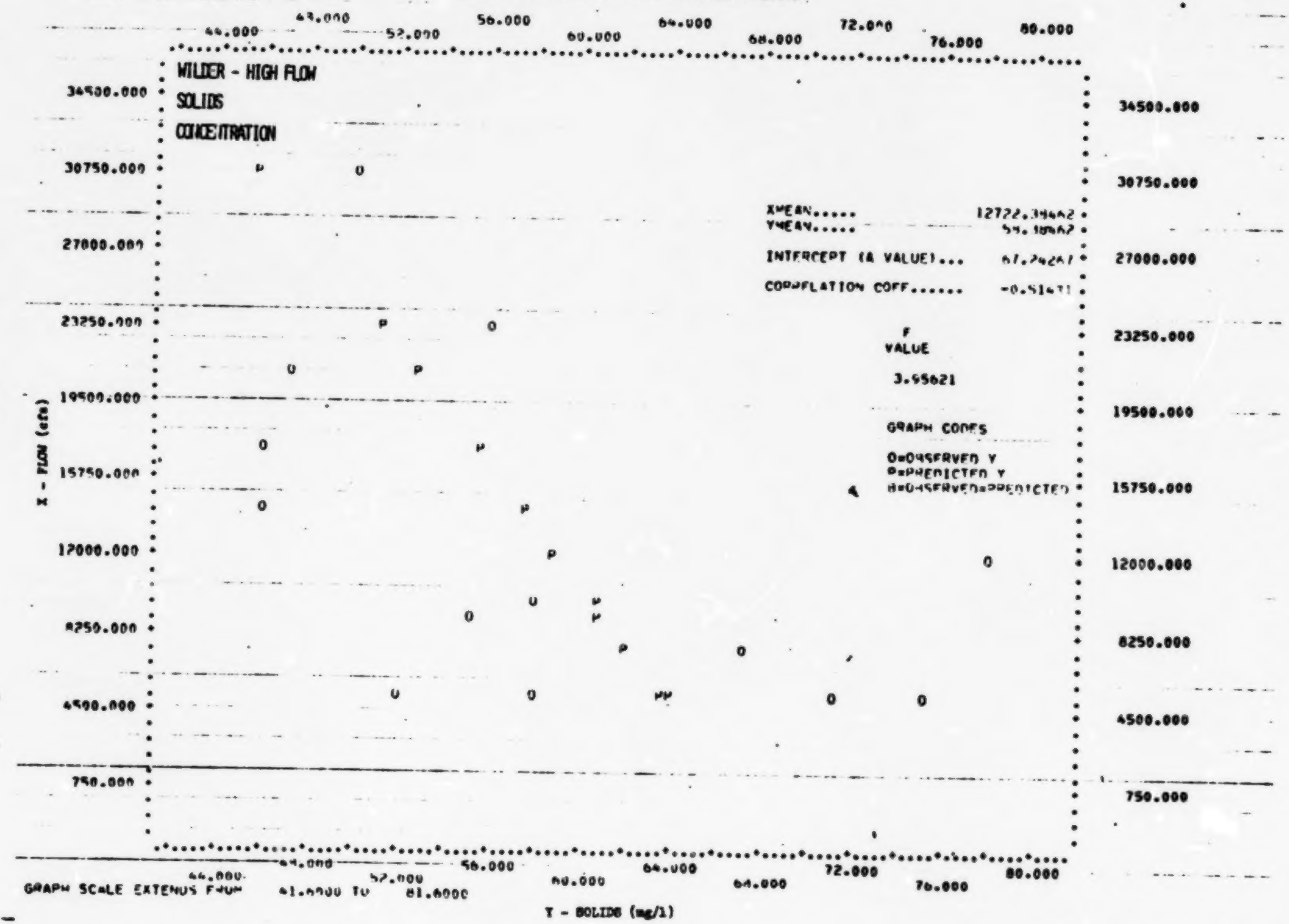
PLOT OF OBSERVED AND PREDICTED VALUES.



PLOT OF OBSERVED AND PREDICTED VALUES.



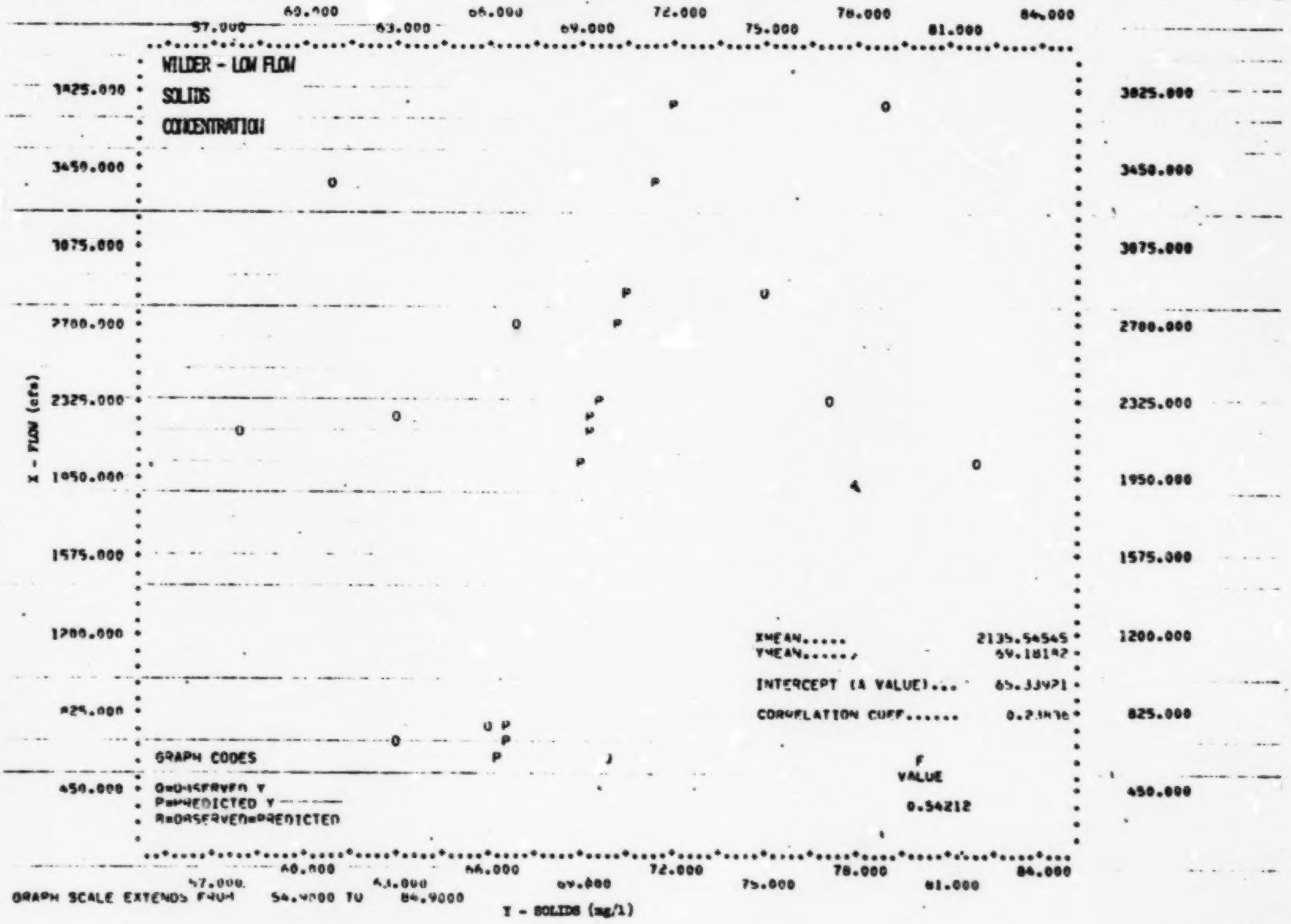
PLOT OF OBSERVED AND PREDICTED VALUES.



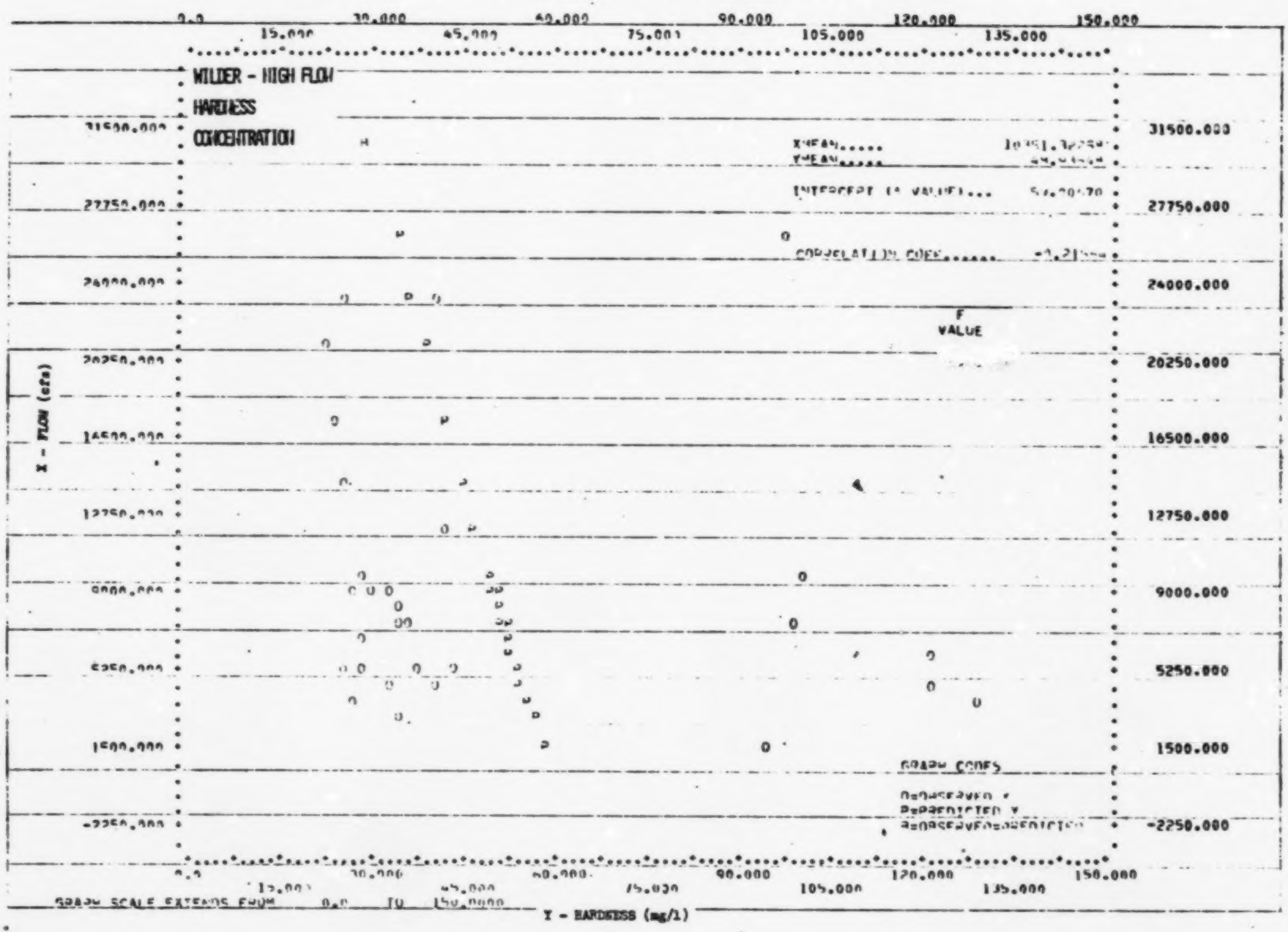
```
XMEAN.....                   12722.39462
YMEAN.....                      59.18462
INTERCEPT (A VALUE)...          67.24267
CORRELATION COFF......          -0.51471

F
VALUE
3.95621
```

GRAPH SCALE EXTENDS FROM 41.6000 TO 81.6000

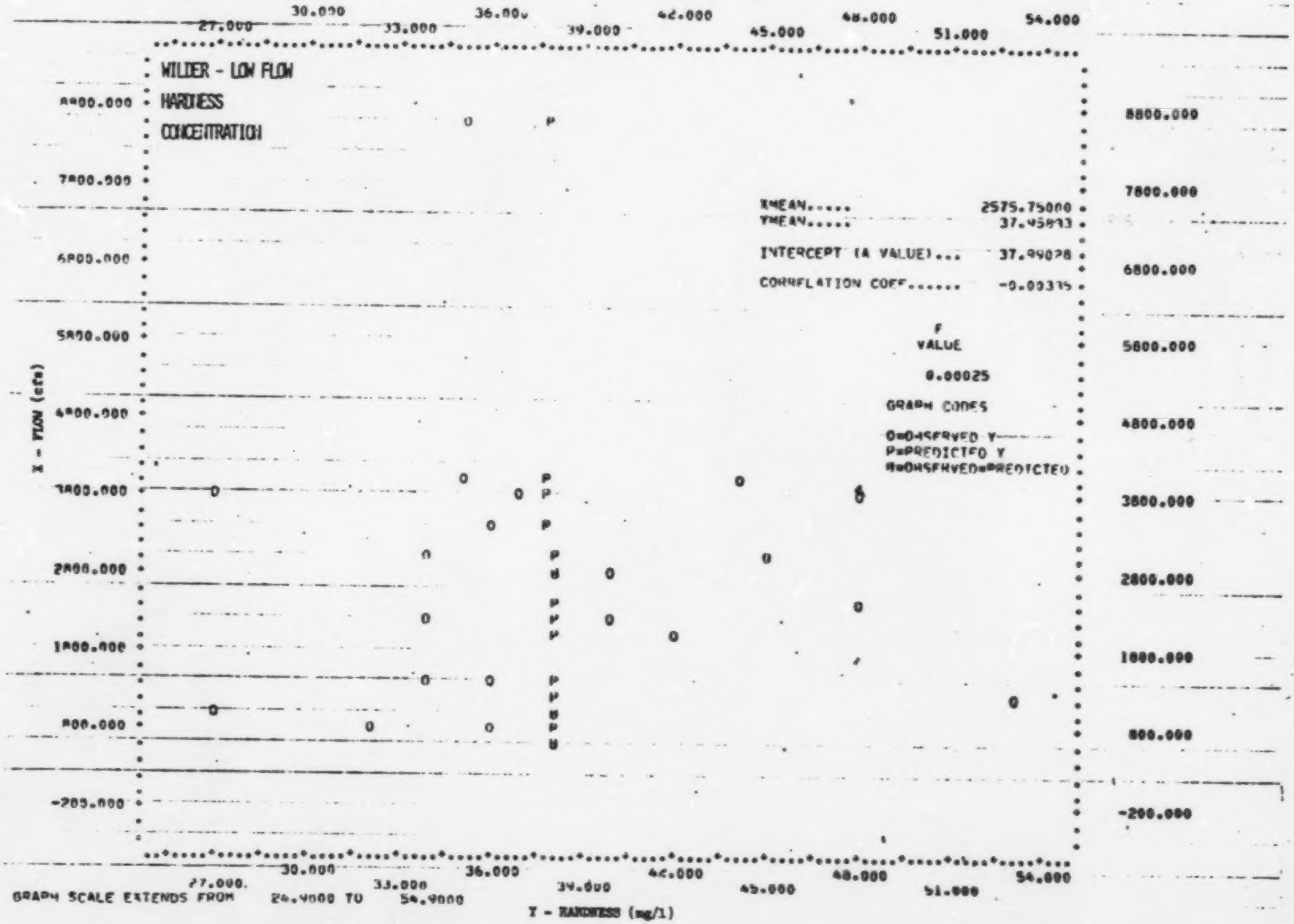
PLOT OF OBSERVED AND PREDICTED VALUES.



PLOT OF OBSERVED AND PREDICTED VALUES.



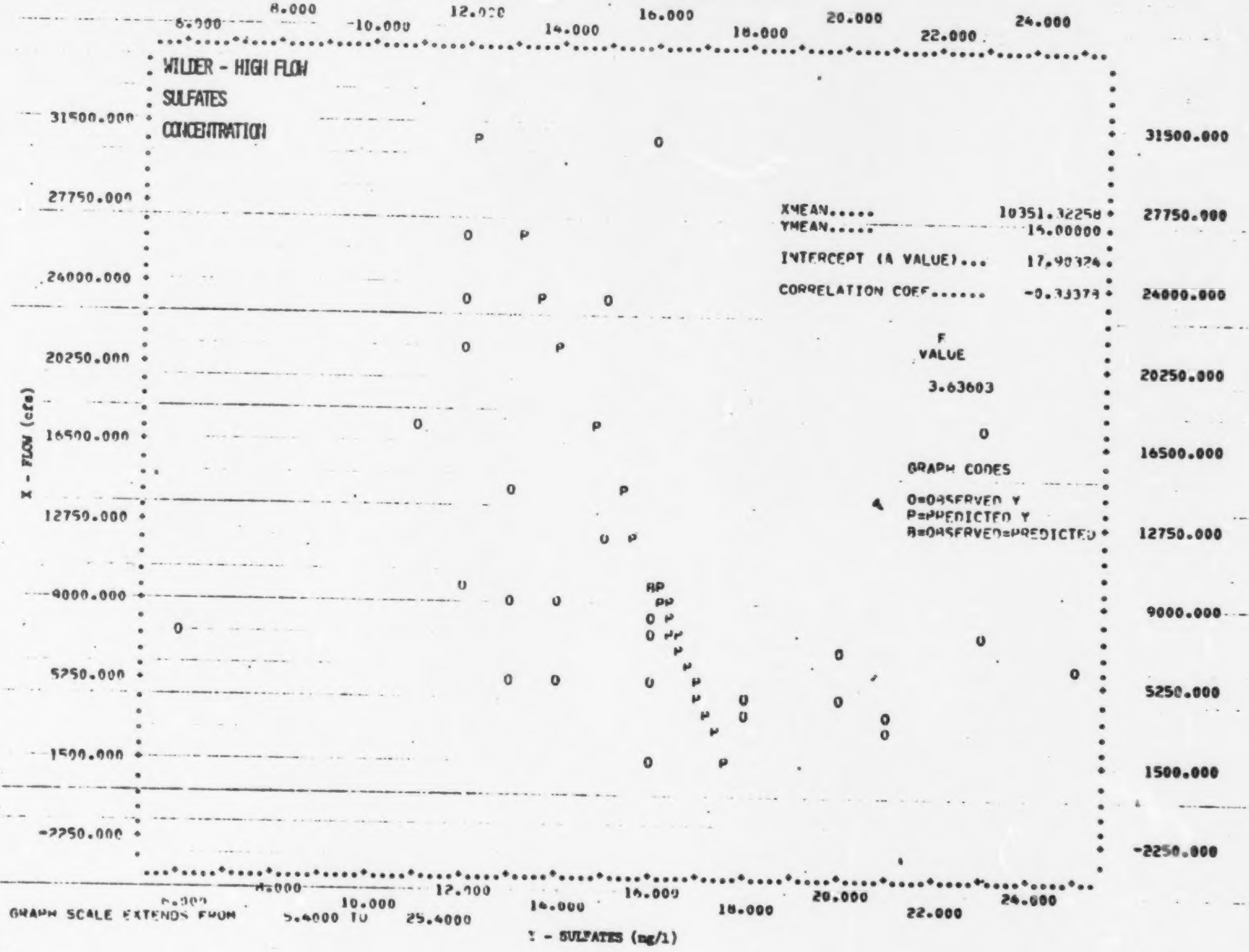
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                 2575.75000
YMEAN.....                   37.45833

INTERCEPT (A VALUE)...       37.94078

CORRELATION COEF.......      -0.00335

        F
      VALUE

     0.00025

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM   24.9000 TO   54.9000

PLOT OF OBSERVED AND PREDICTED VALUES.



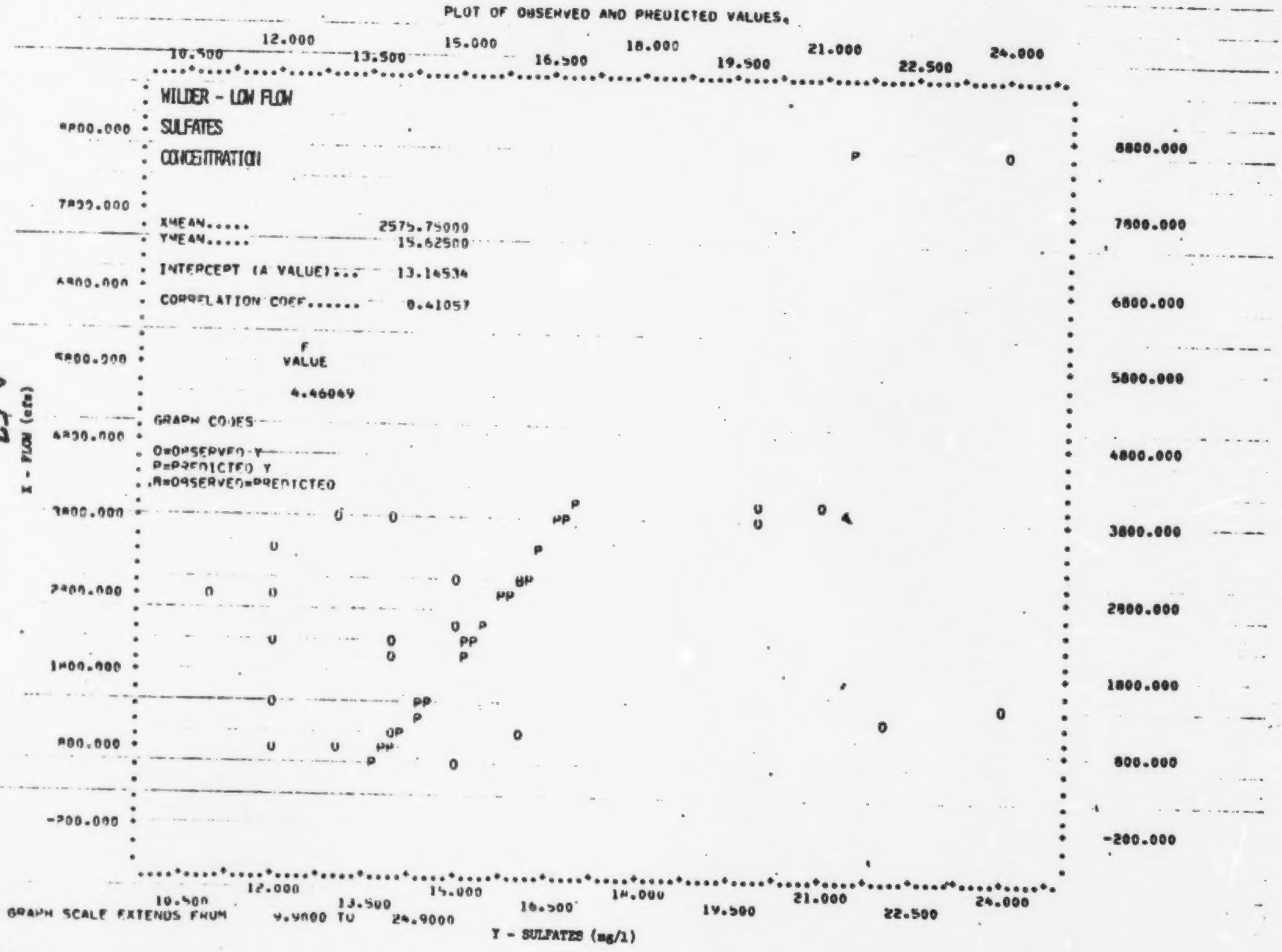
XMEAN..... 10351.32258
YMEAN..... 15.00000
INTERCEPT (A VALUE)... 17.90324
CORRELATION COEF...... -0.33379

F
VALUE
3.63603

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM 5.4000 TO 25.4000



PLOT OF OBSERVED AND PREDICTED VALUES.

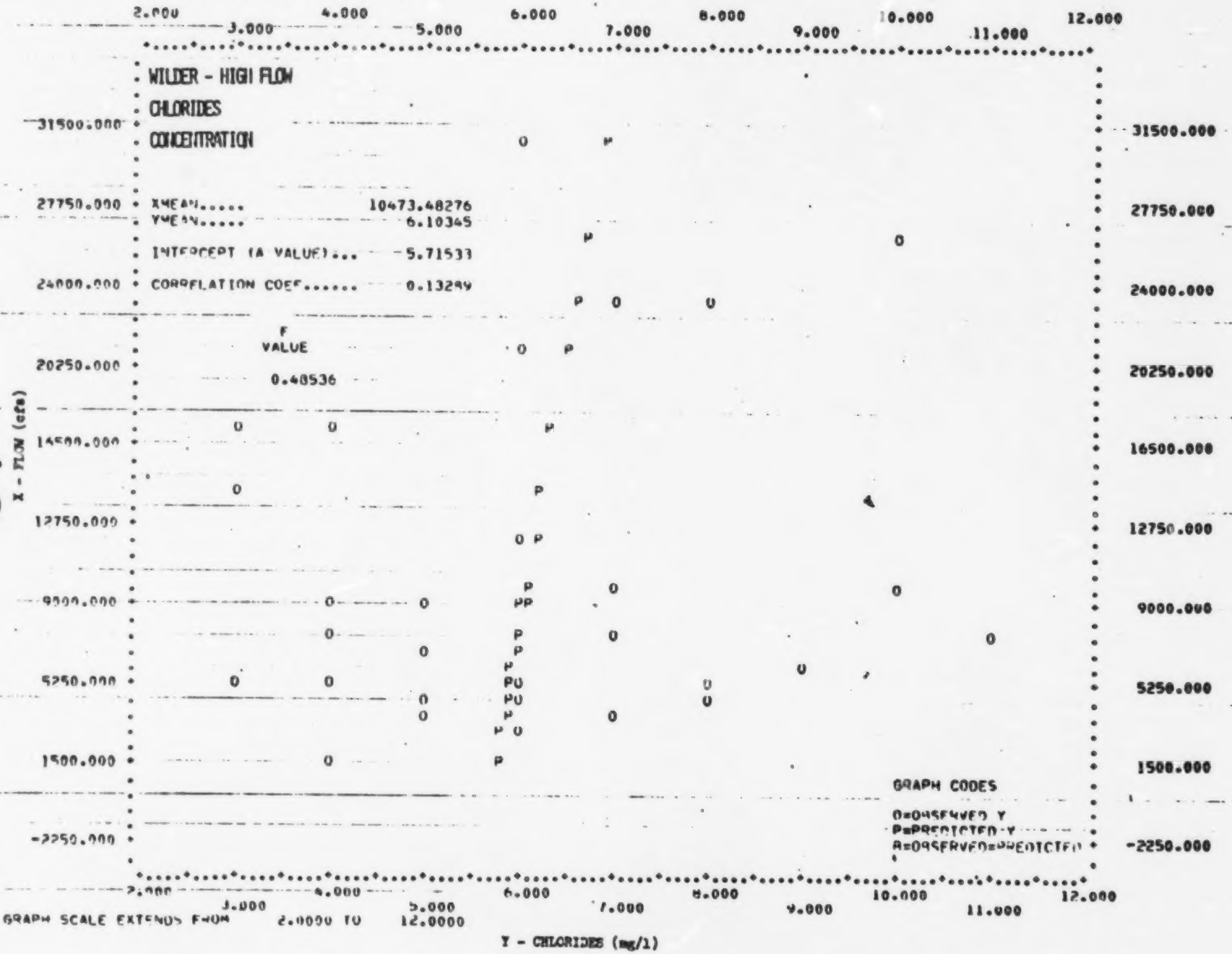
WILDER - LOW FLOW
SULFATES
CONCENTRATION

```
XMEAN.....                 2575.75000
YMEAN.....                   15.62500
INTERCEPT (A VALUE)...       13.14534
CORRELATION COEF.......       0.41057

       F
     VALUE

    4.46049

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
A=OBSERVED=PREDICTED
```

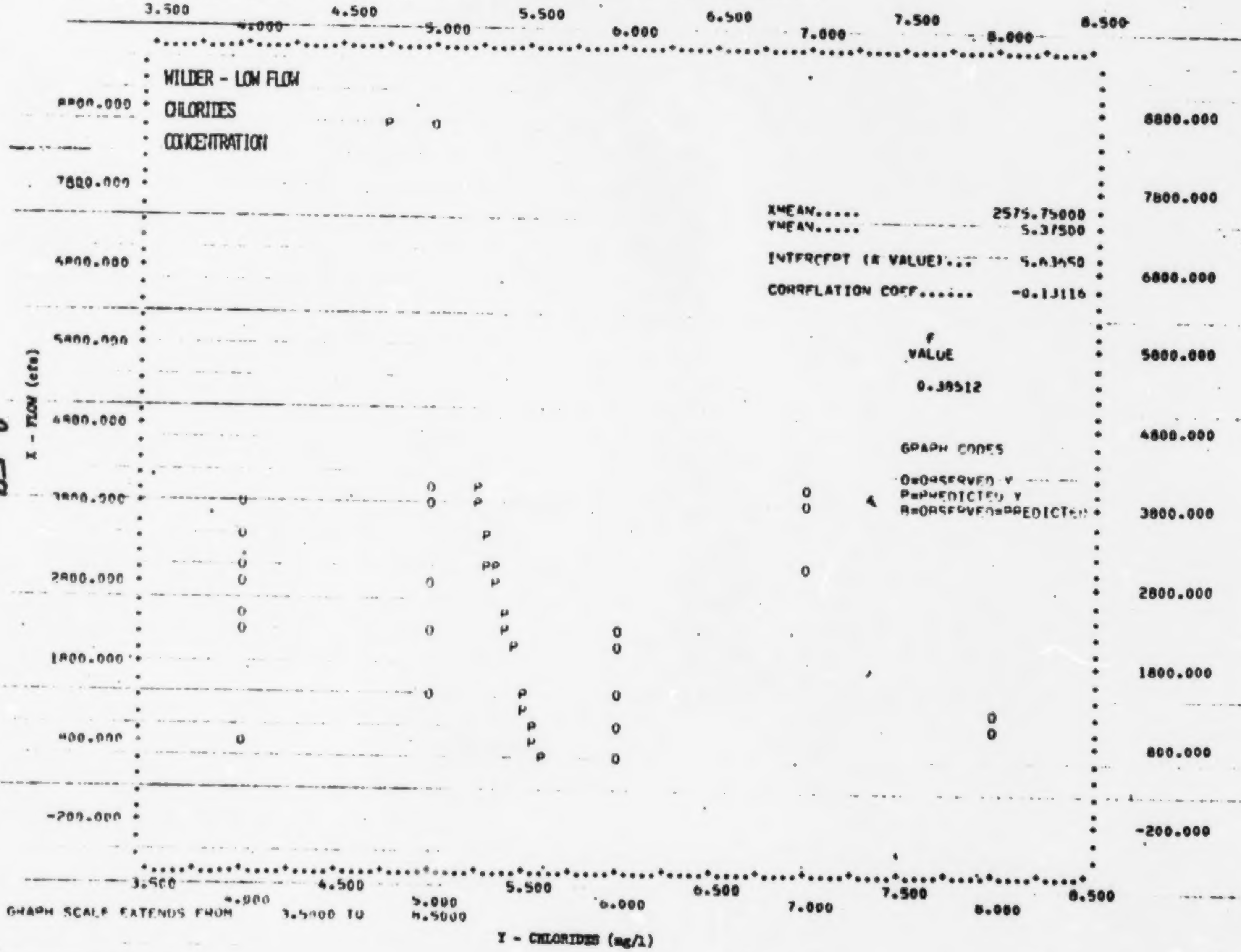
GRAPH SCALE EXTENDS FROM 9.9000 TO 24.9000

A-57
A-57

PLOT OF OBSERVED AND PREDICTED VALUES.



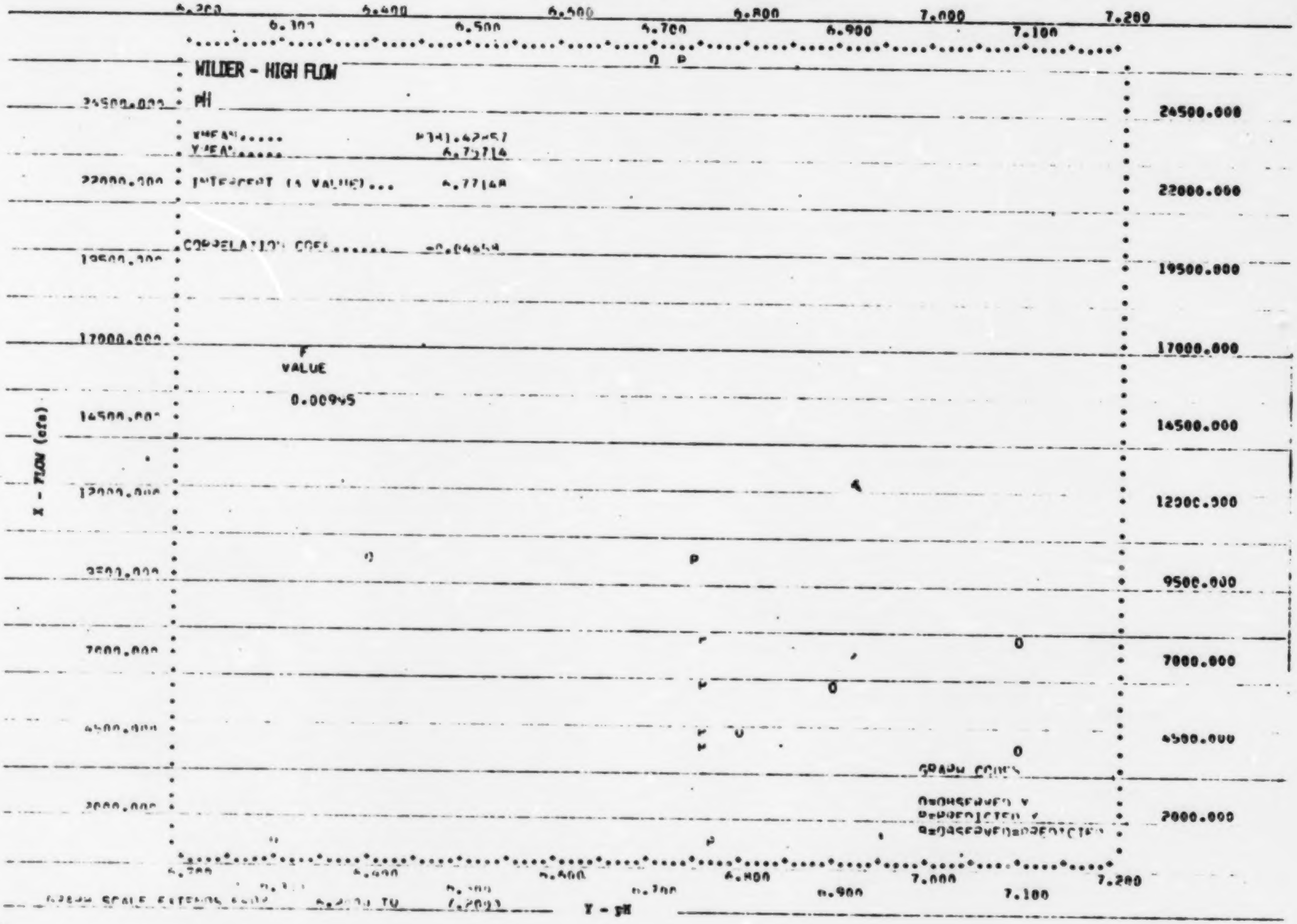
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                 2575.75000
YMEAN.....                    5.37500

INTERCEPT (A VALUE)...        5.63650

CORRELATION COEF......       -0.13116

            F
          VALUE

         0.38512

        GRAPH CODES

        0=OBSERVED Y
        P=PREDICTED Y
        B=OBSERVED=PREDICTED
```

GRAPH SCALE EXTENDS FROM 3.5000 TO 8.5000

PLOT OF OBSERVED AND PREDICTED VALUES.



WILDER - HIGH FLOW

pH

XMEAN..... 8341.42857
YMEAN..... 6.75714

INTERCEPT (A VALUE)... 6.77148

CORRELATION COEF....... -0.04454

F VALUE 0.00945

GRAPH CODES

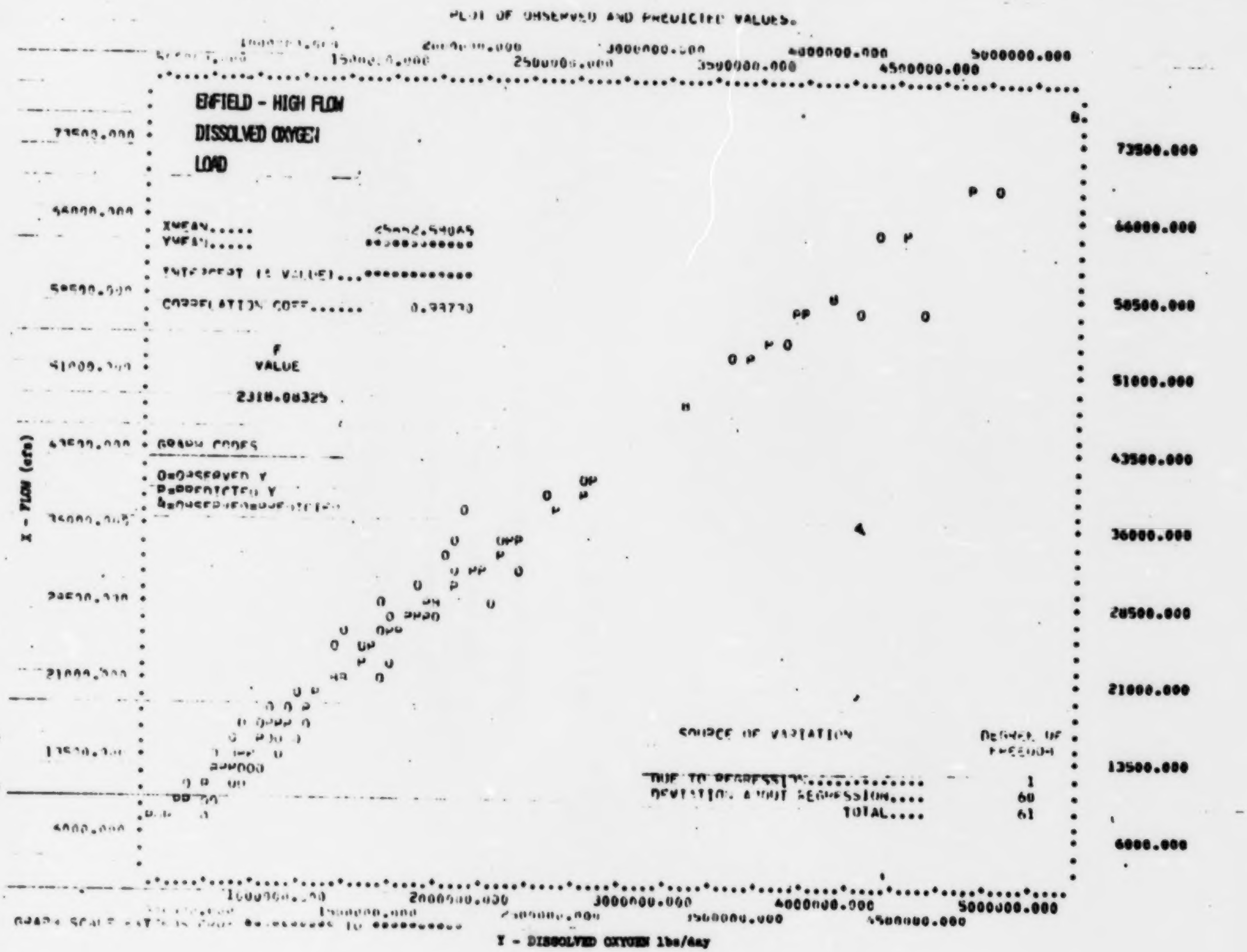
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM 6.2000 TO 7.2000

APPENDIX B

Linear Regressions Comparing
Stream Flow to Load
for Various Parameters

PLOT OF OBSERVED AND PREDICTED VALUES.



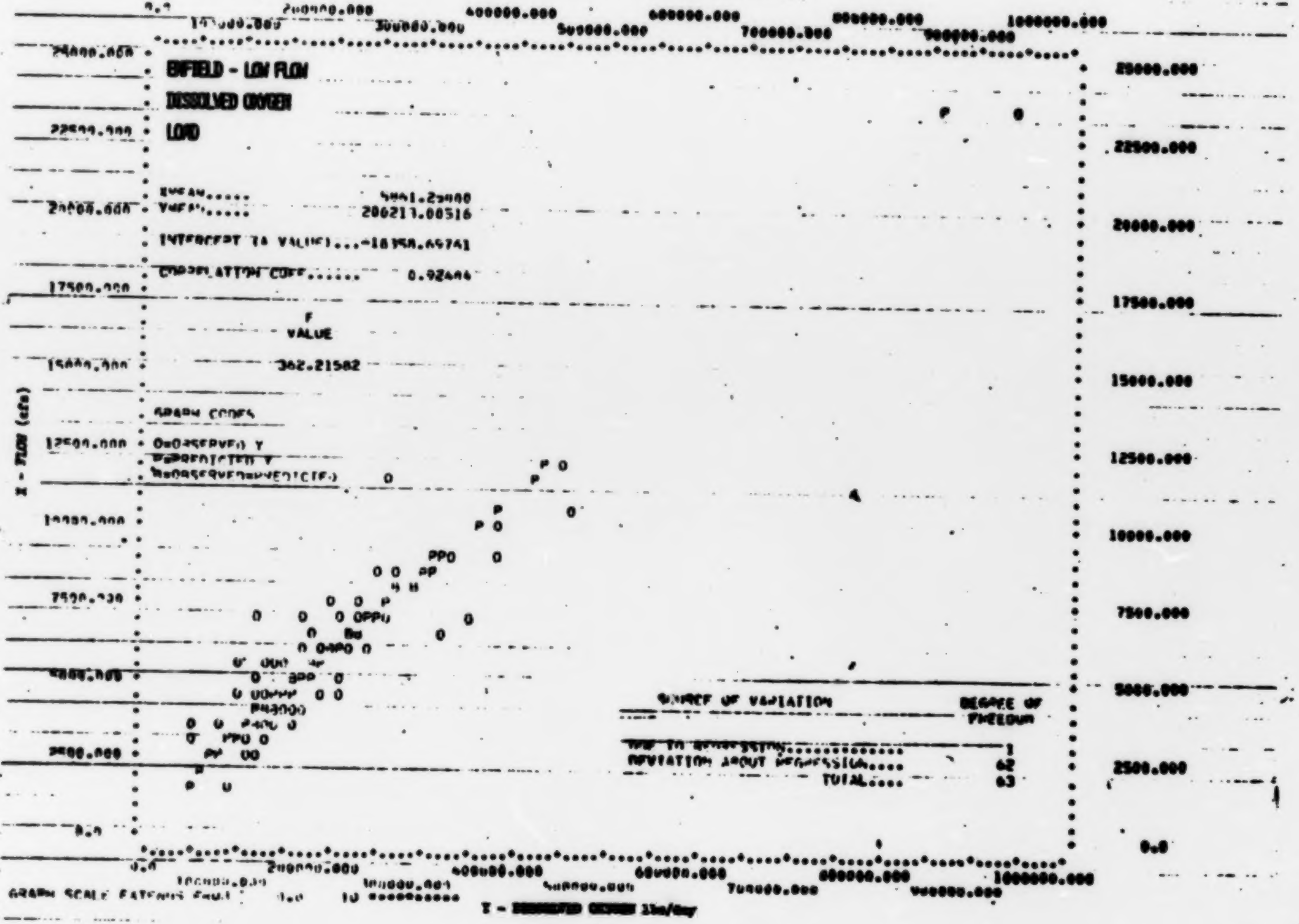
ENFIELD - HIGH FLOW
DISSOLVED OXYGEN
LOAD

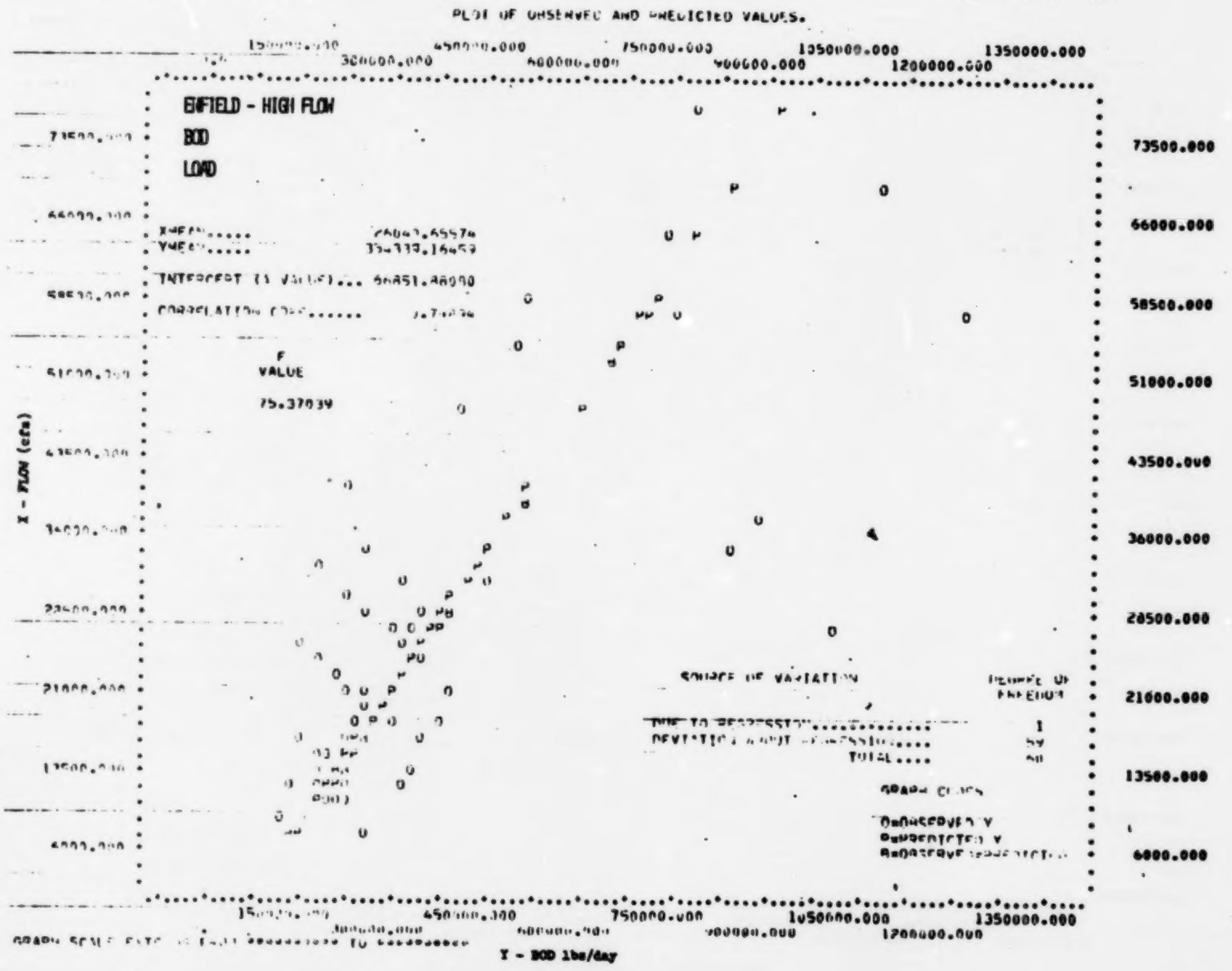
```
XMEAN.....                25992.54065
YMEAN.....                ************
INTERCEPT (Y VALUE)...************
CORRELATION COEFF.......     0.98730

          F
        VALUE

      2318.08325
```

```
SOURCE OF VARIATION                          DEGREE OF
                                              FREEDOM
DUE TO REGRESSION...............                1
DEVIATION ABOUT REGRESSION....                 60
                        TOTAL....               61
```

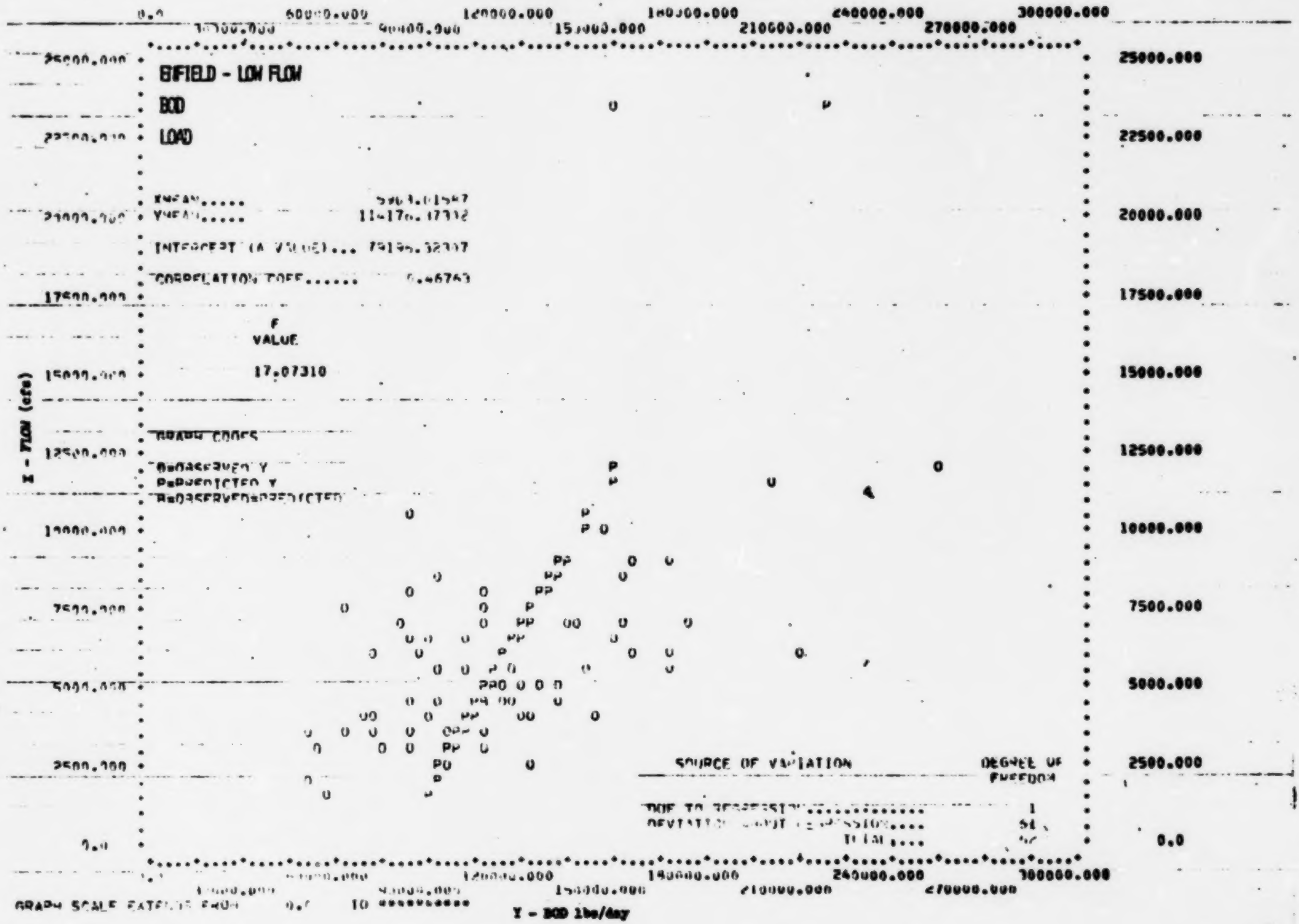
GRAPH SCALE RATIO IS FROM ********* TO *********

PLOT OF OBSERVED AND PREDICTED VALUES.



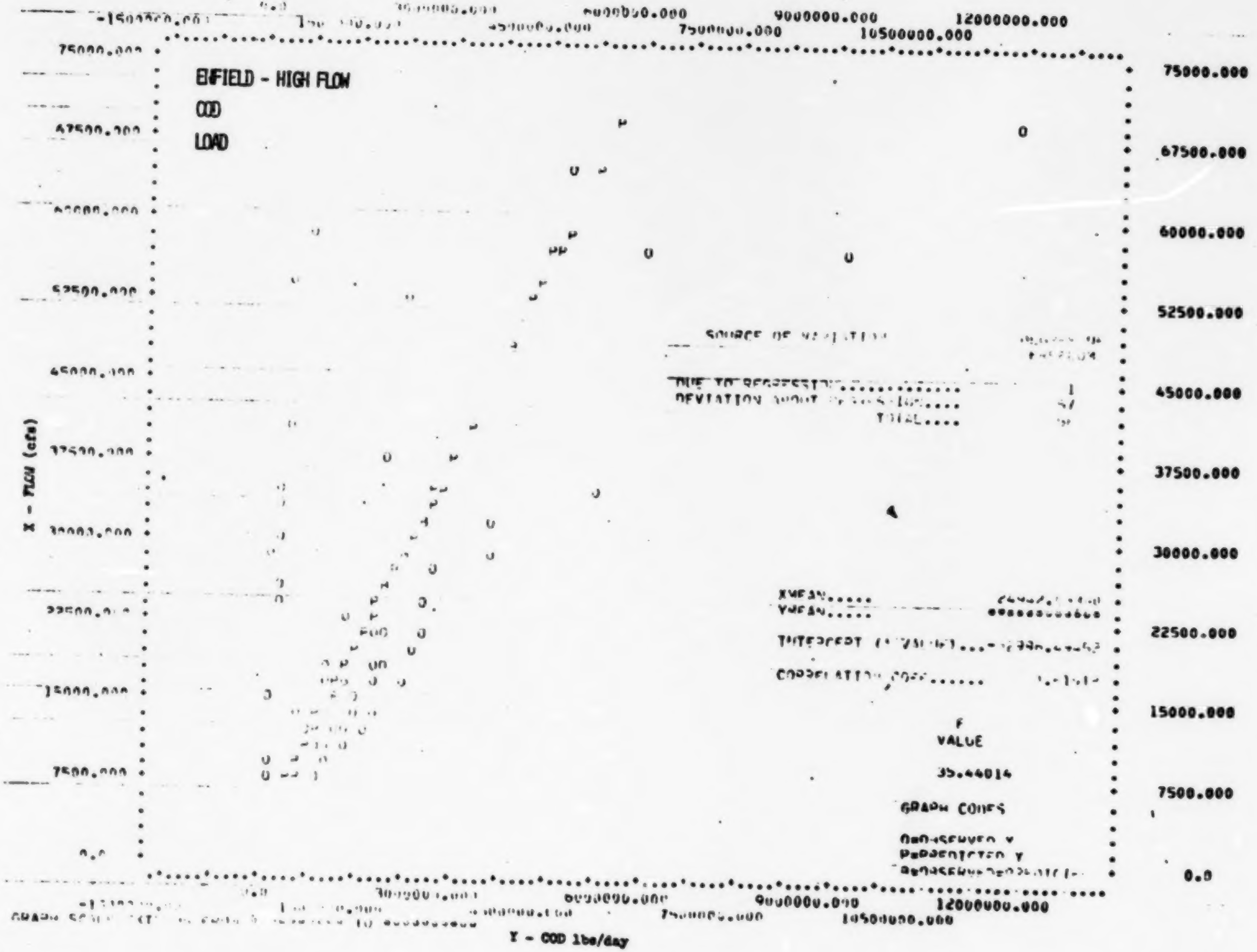

PLOT OF OBSERVED AND PREDICTED VALUES.
ENFIELD - HIGH FLOW
BOD
LOAD
XMEAN..... 26047.65574
YMEAN..... 354333.16459
INTERCEPT (A VALUE)... 56851.88090
CORRELATION COEF.......
F
VALUE
75.37039
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION.............. 1
DEVIATION ABOUT REGRESSION..... 59
TOTAL.... 60
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED-PREDICTED
150000.000
300000.000
450000.000
600000.000
750000.000
900000.000
1050000.000
1200000.000
1350000.000
73500.000
66000.000
58500.000
51000.000
43500.000
36000.000
28500.000
21000.000
13500.000
6000.000
X - FLOW (cfs)
Y - BOD lbs/day
GRAPH SCALE EXTENDS FROM

PLOT OF OBSERVED AND PREDICTED VALUES.



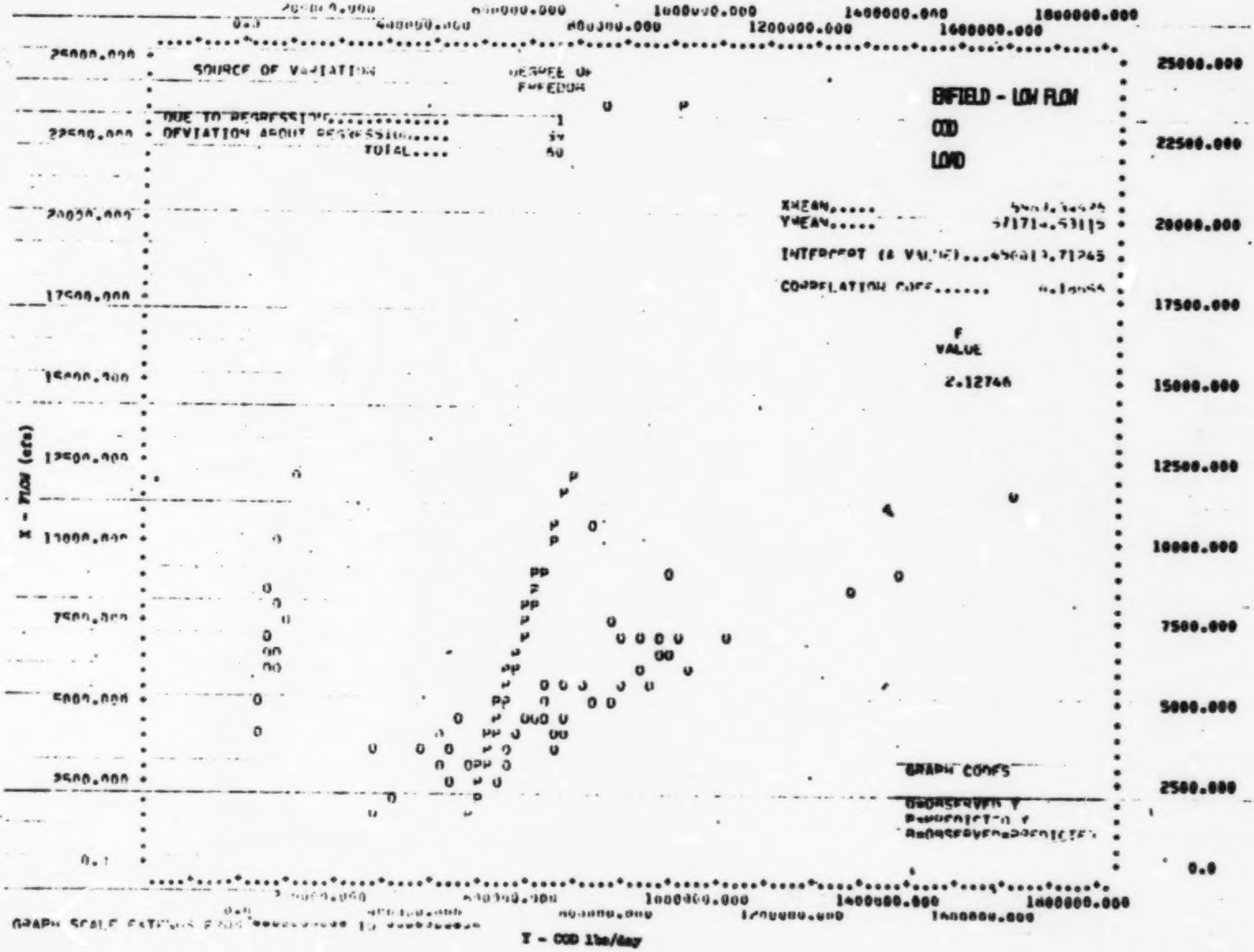
```
XMEAN.....                 5961.01587
YMEAN.....               114170.17332
INTERCEPT (A VALUE)...    79195.32307
CORRELATION COEF......        0.46763

        F
      VALUE
    17.07310

SOURCE OF VARIATION                          DEGREE OF
                                              FREEDOM
DUE TO REGRESSION.................               1
DEVIATION ABOUT REGRESSION....                  51
                        TOTAL....               52

GRAPH SCALE EXTENDS FROM     0.0     TO **********
```

PLOT OF OBSERVED AND PREDICTED VALUES.



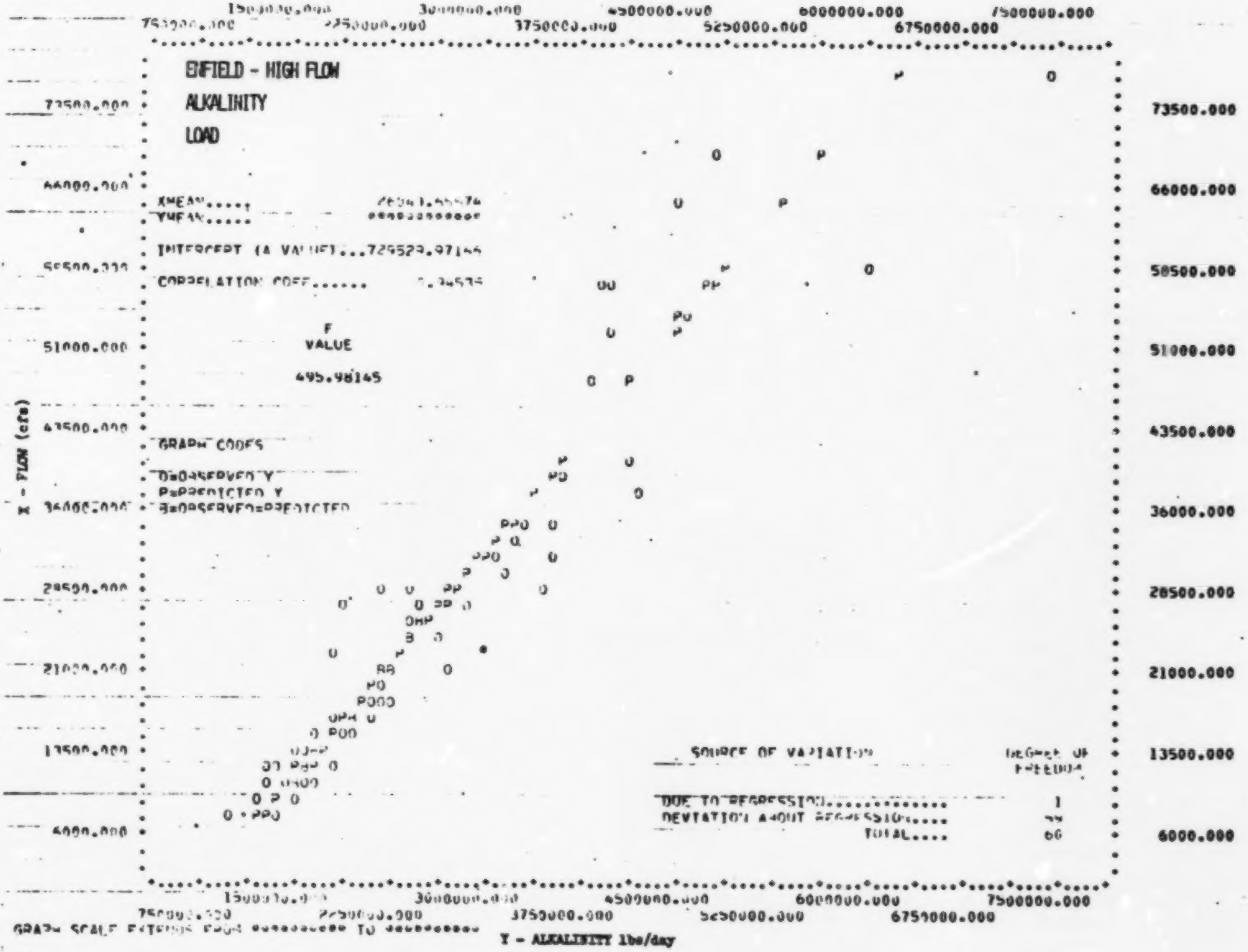
```
SOURCE OF VARIATION                       DEGREES OF
                                          FREEDOM

DUE TO REGRESSION..............               1
DEVIATION ABOUT REGRESSION....               57
                     TOTAL....               58

XMEAN.....                         [illegible]
YMEAN.....                         [illegible]

INTERCEPT (A VALUE)...             [illegible]

CORRELATION COEF.......            [illegible]

               F
             VALUE

           35.44014
```

PLOT OF OBSERVED AND PREDICTED VALUES.



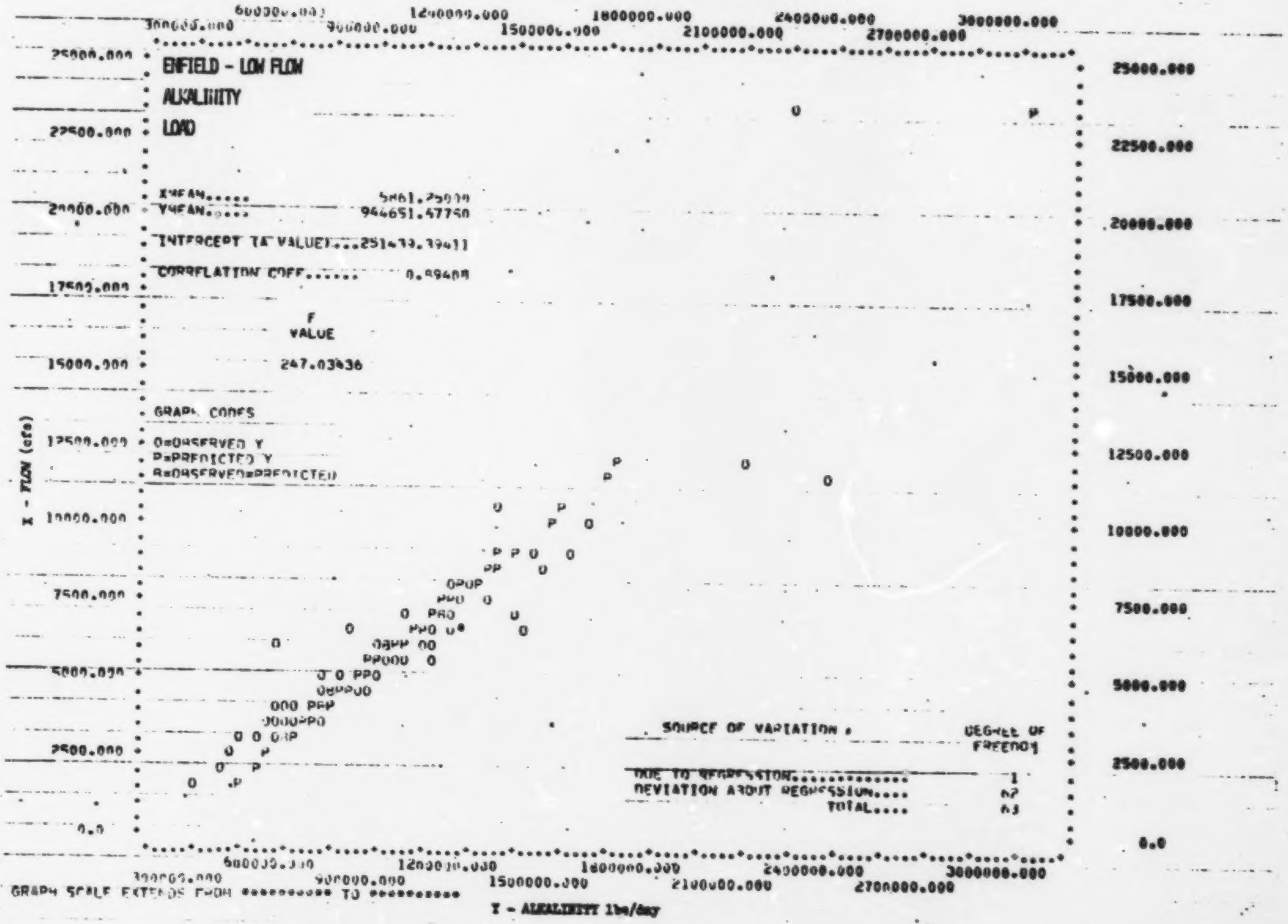
```
SOURCE OF VARIATION                    DEGREE OF
                                        FREEDOM

DUE TO REGRESSION.................         1
DEVIATION ABOUT REGRESSION.....           59
                         TOTAL....        60

XMEAN.....                       [illegible]
YMEAN.....                      571714.53115

INTERCEPT (A VALUE)...456013.71245

CORRELATION COEF......      [illegible]

     F
   VALUE

  2.12746
```

PLOT OF OBSERVED AND PREDICTED VALUES.



```
ENFIELD - HIGH FLOW
ALKALINITY
LOAD

XMEAN.....          2694?.55574
YMEAN.....          ************

INTERCEPT (A VALUE)...729529.97144

CORRELATION COEF.......     0.94535

              F
            VALUE

          495.98145

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

SOURCE OF VARIATION                      DEGREE OF
                                          FREEDOM

DUE TO REGRESSION..................          1
 DEVIATION ABOUT REGRESSION.......        [illegible]
                          TOTAL....         66

GRAPH SCALE EXTENDS FROM ********** TO **********
```

PLOT OF OBSERVED AND PREDICTED VALUES.



ENFIELD - LOW FLOW

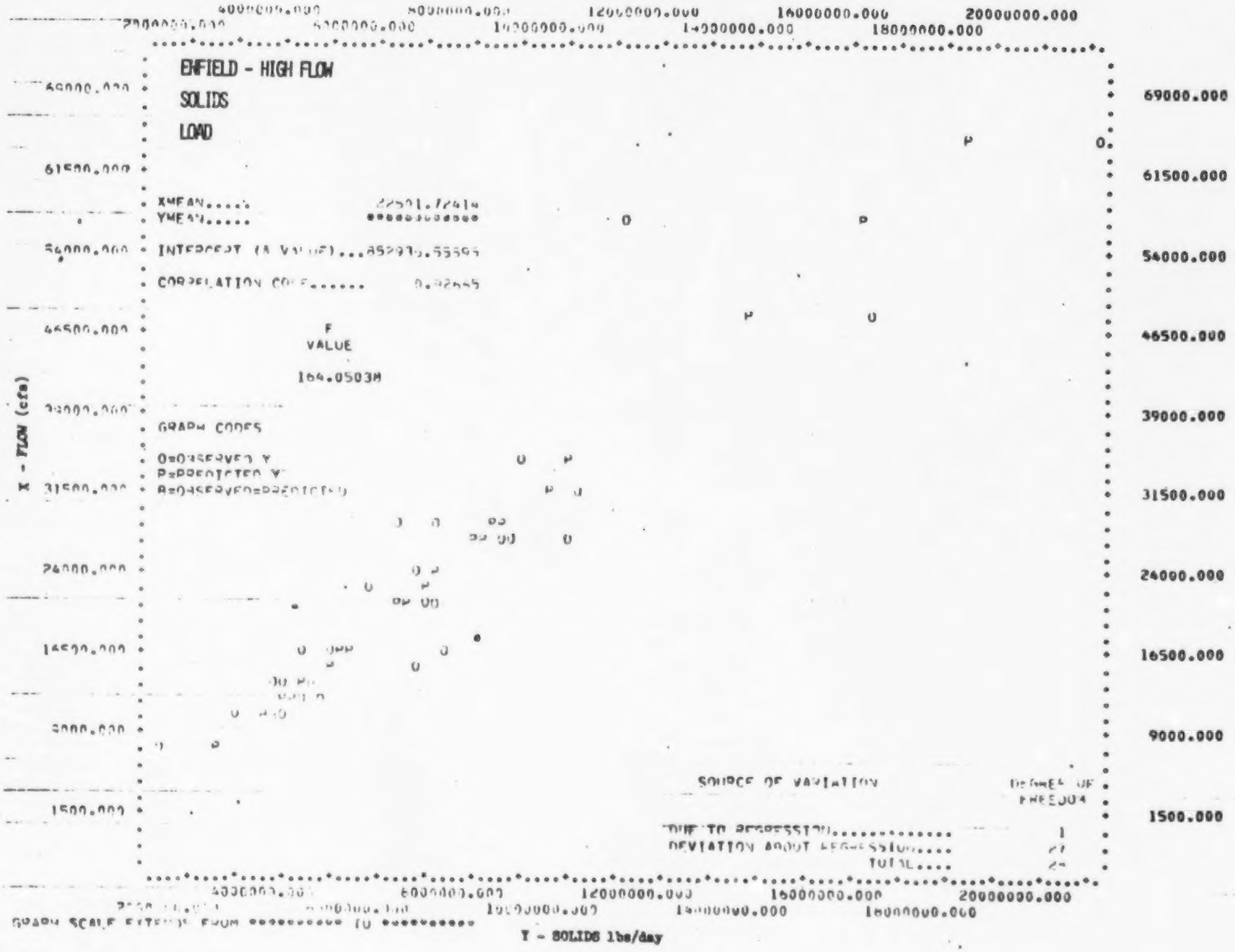
ALKALINITY

LOAD

```
XMEAN.....                 5861.25000
YMEAN.....               944651.47750
INTERCEPT (A VALUE)....251473.39411
CORRELATION COEFF.......      0.99408

          F
        VALUE
      247.03436

GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

SOURCE OF VARIATION .                  DEGREE OF
                                        FREEDOM
DUE TO REGRESSION..................        1
DEVIATION ABOUT REGRESSION....            62
                         TOTAL....        63
```

GRAPH SCALE EXTENDS FROM ********** TO **********

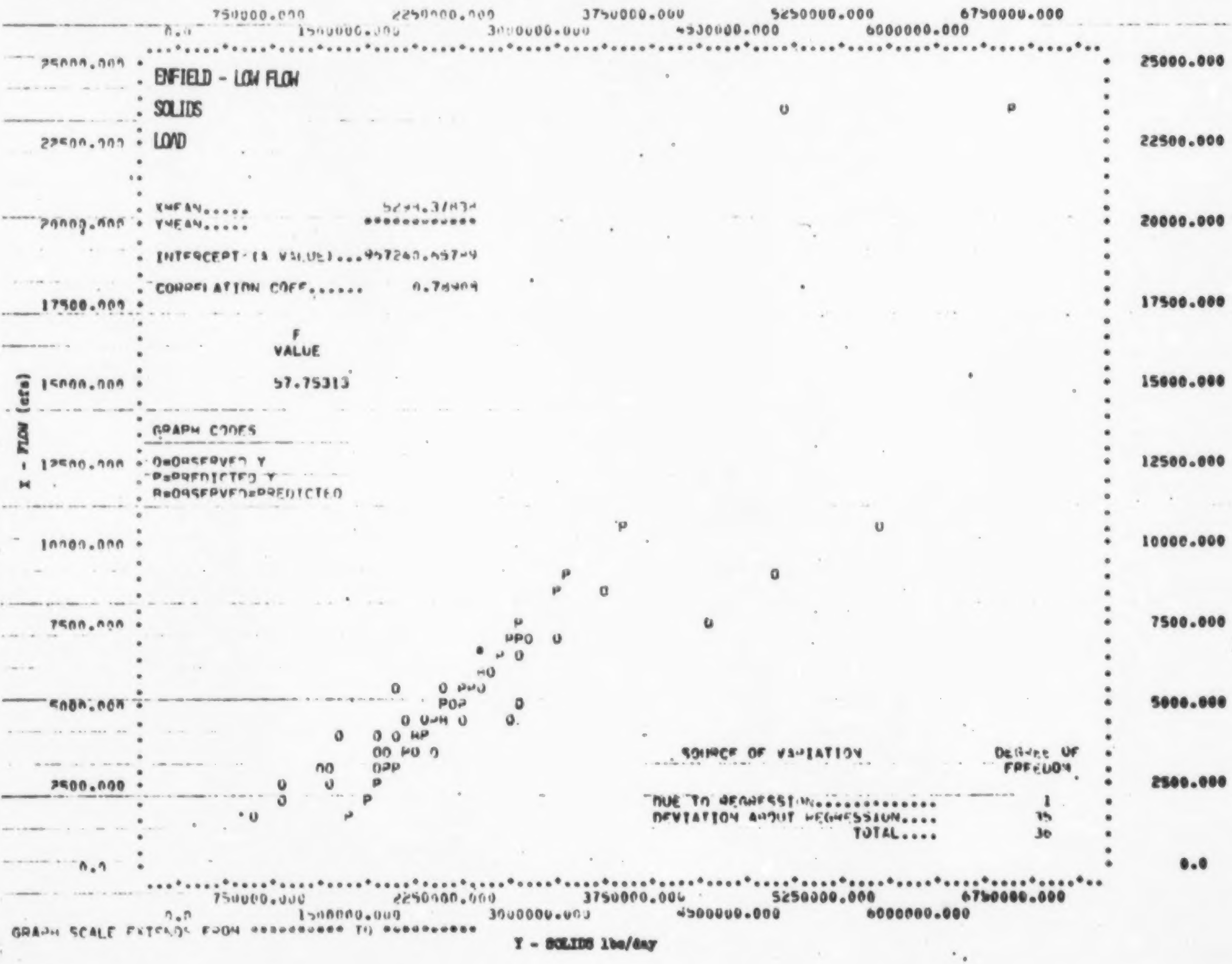
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                  22501.72414
YMEAN.....                  ************
INTERCEPT (A VALUE)...852975.55595
CORRELATION COEF......      0.92655

          F
        VALUE

      164.05038

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

SOURCE OF VARIATION                       DEGREES OF
                                            FREEDOM

DUE TO REGRESSION...............              1
DEVIATION ABOUT REGRESSION......             27
                        TOTAL....            28

GRAPH SCALE EXTENDS FROM ********** TO **********
```

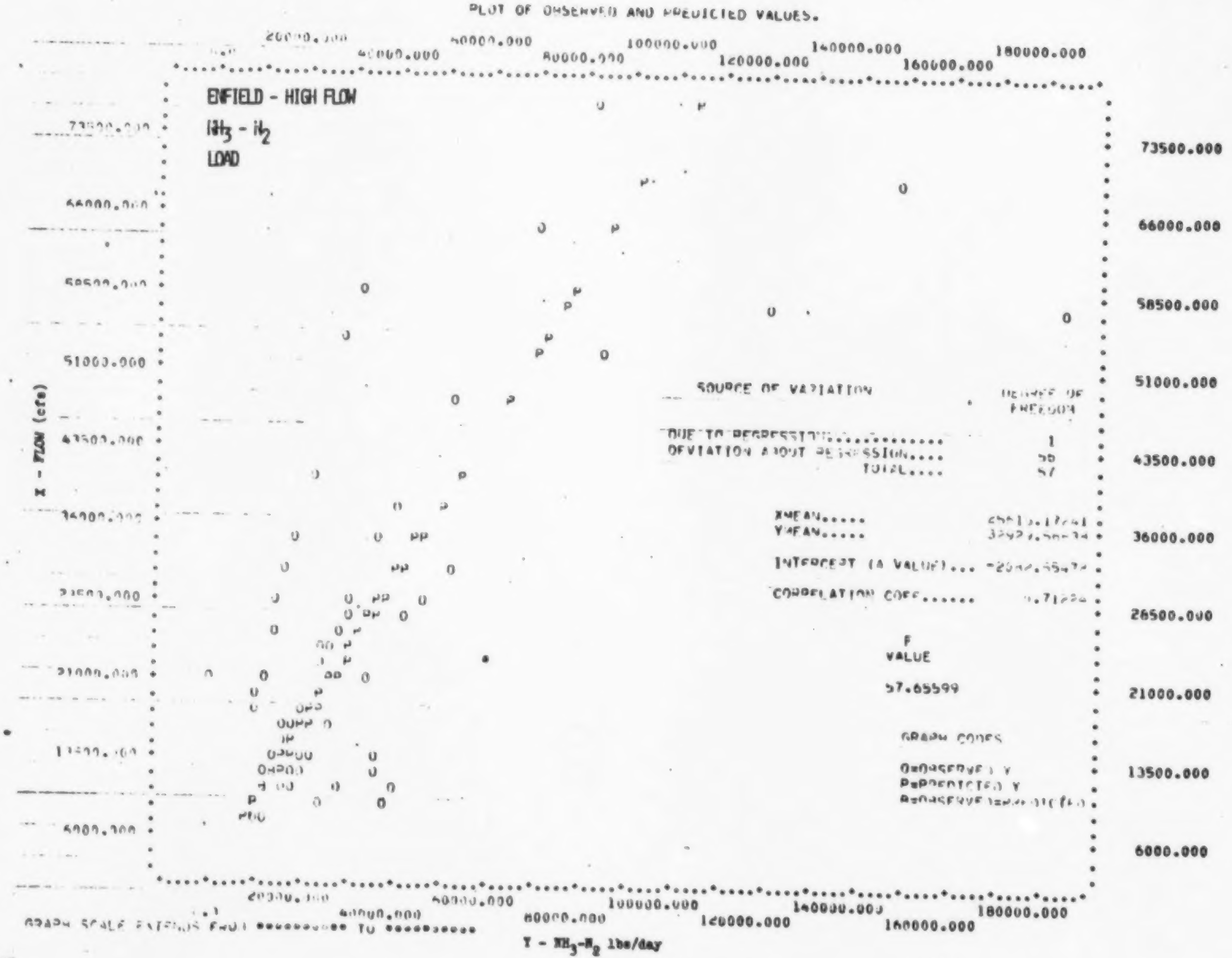
B-10

PLOT OF OBSERVED AND PREDICTED VALUES.

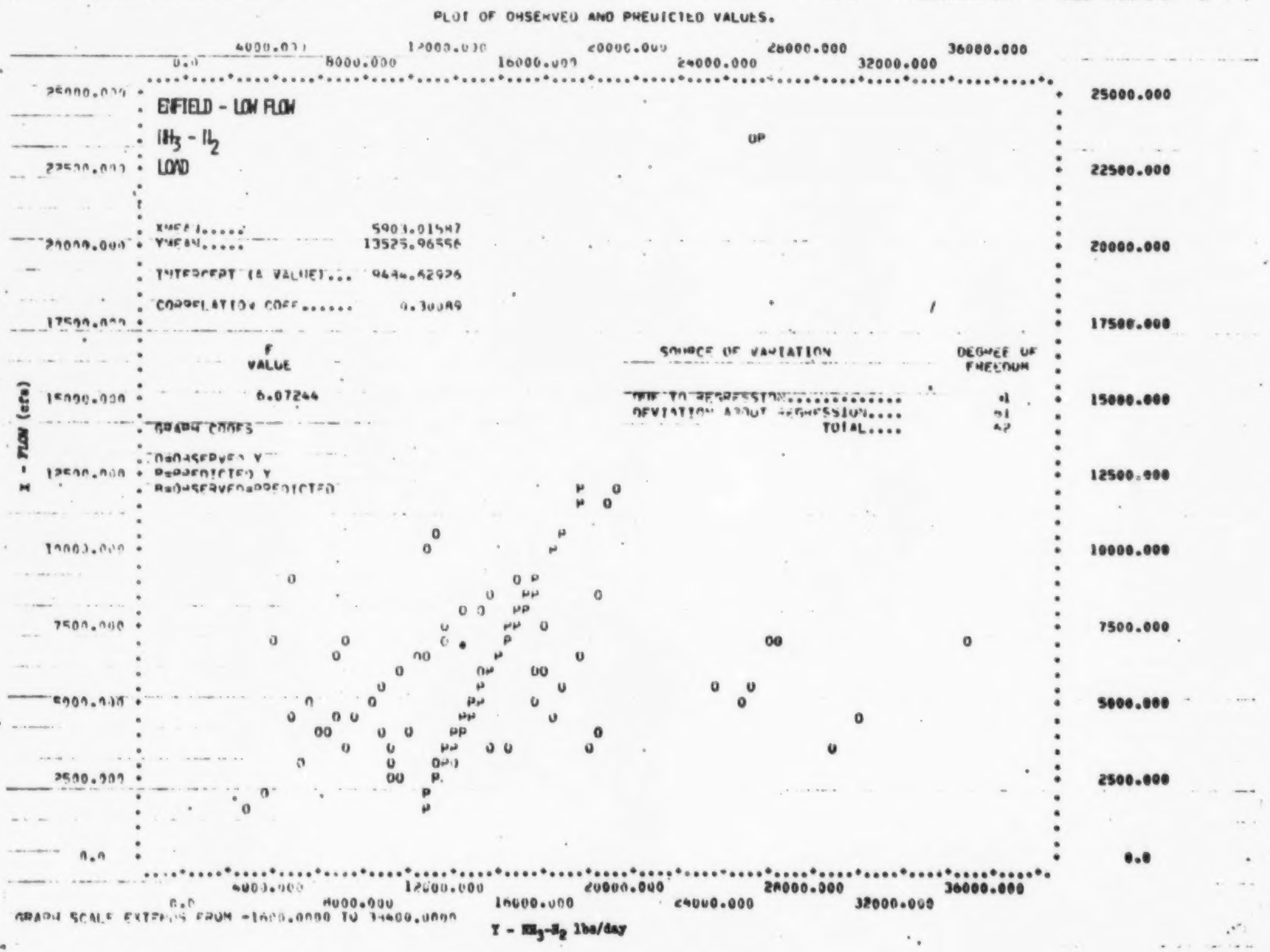


```
ENFIELD - LOW FLOW
SOLIDS
LOAD

XMEAN.....          5244.37834
YMEAN.....        ************

INTERCEPT (A VALUE)...957240.65749

CORRELATION COEF......     0.78909

            F
          VALUE

         57.75313

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
R=OBSERVED=PREDICTED

SOURCE OF VARIATION                       DEGREE OF
                                           FREEDOM

DUE TO REGRESSION................              1
DEVIATION ABOUT REGRESSION....                35
                       TOTAL....              36
```

GRAPH SCALE EXTENDS FROM ********** TO **********



```
SOURCE OF VARIATION                          DEGREES OF
                                               FREEDOM

DUE TO REGRESSION.................                1
DEVIATION ABOUT REGRESSION....                   56
                         TOTAL....               57


             XMEAN.....                 65613.17641
             YMEAN.....                 32927.50634

             INTERCEPT (A VALUE)... -20442.55474

             CORRELATION COEF......      0.71224


                        F
                      VALUE

                    57.65599


                      GRAPH CODES

                      O=OBSERVED Y
                      P=PREDICTED Y
                      B=OBSERVED=PREDICTED
```

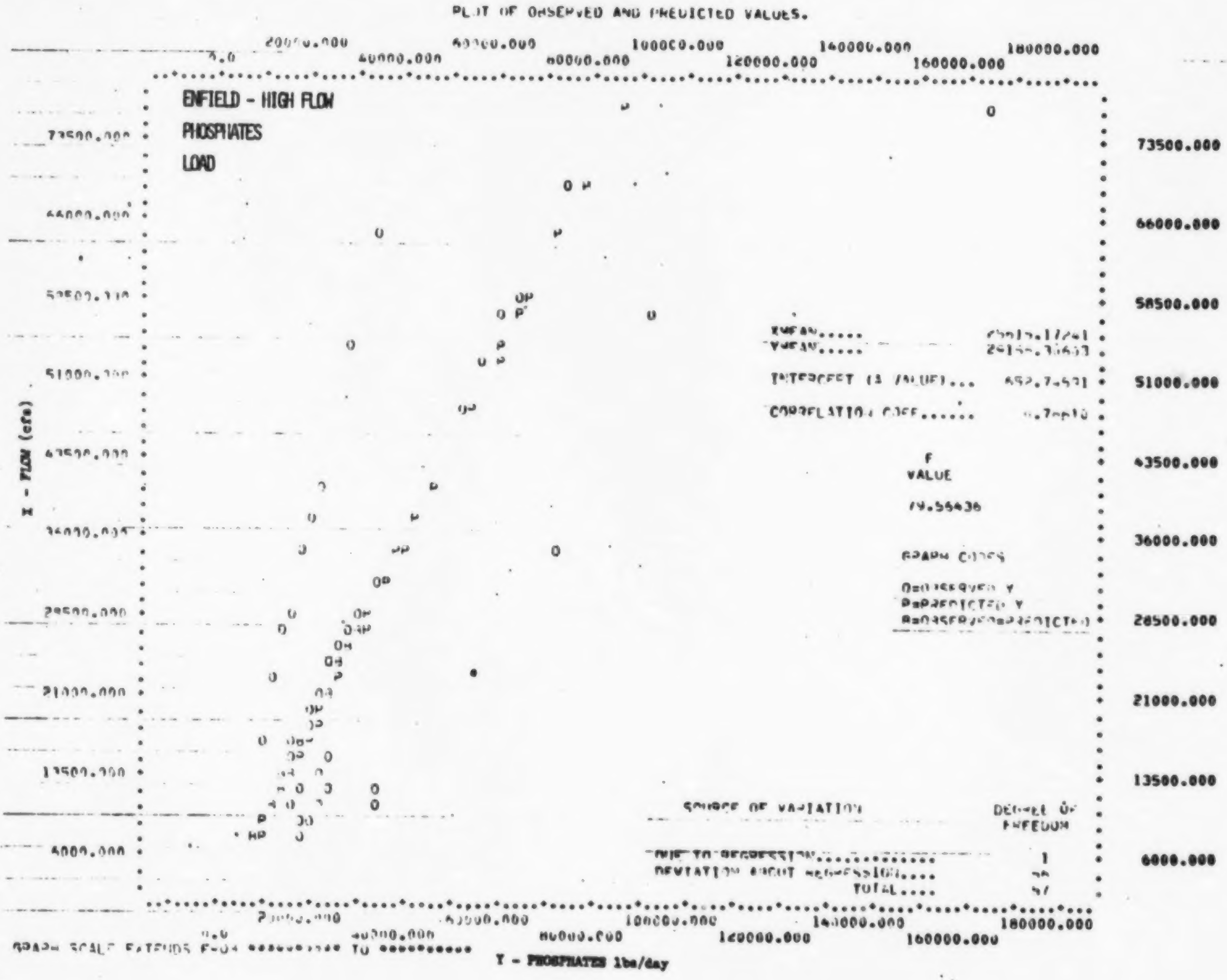


PLOT OF OBSERVED AND PREDICTED VALUES.

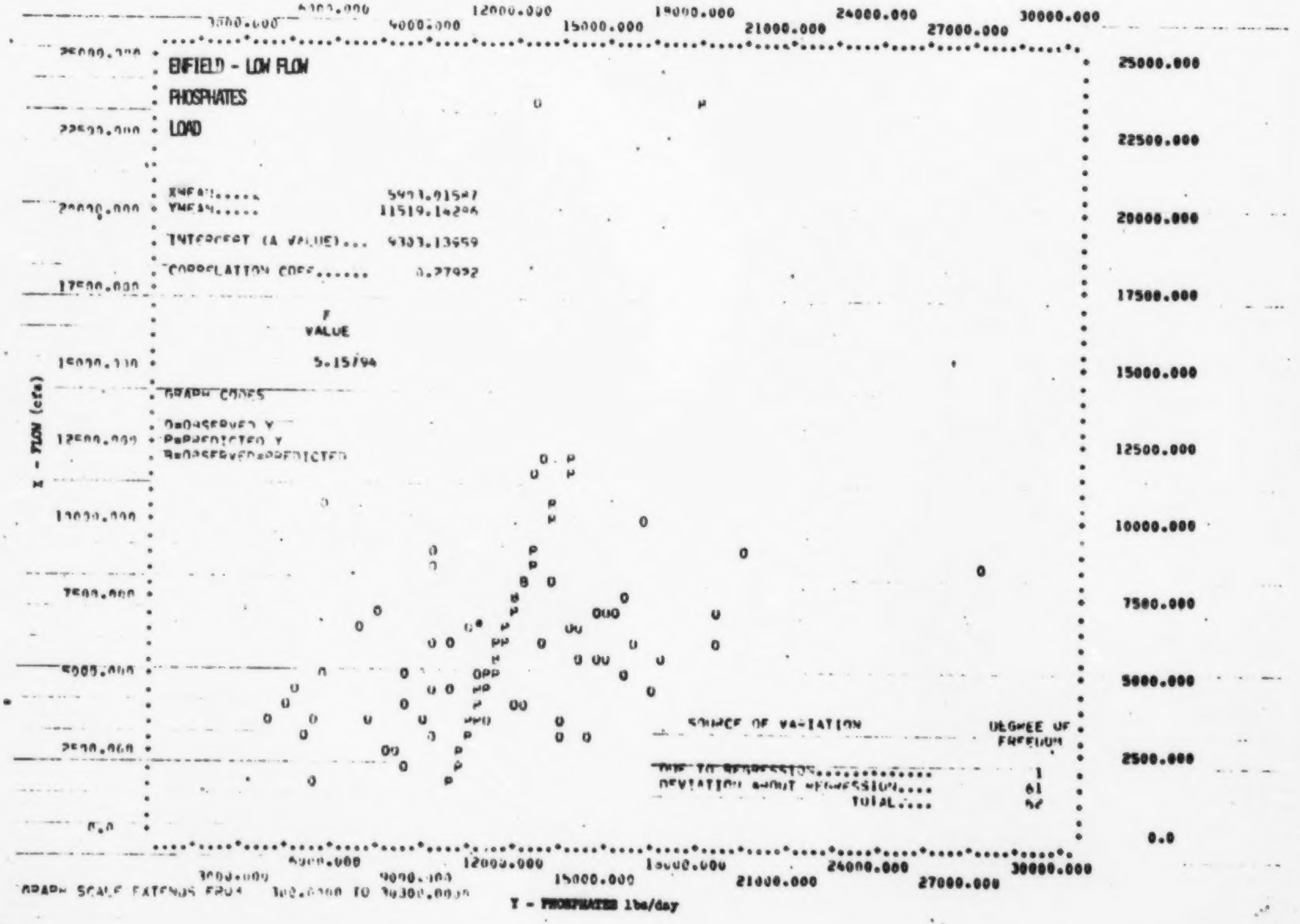
```
ENFIELD - LOW FLOW
NH3 - N2
LOAD

XMEAN.....              5903.01587
YMEAN.....             13525.96556

INTERCEPT (A VALUE)...  9444.62926

CORRELATION COEF......     0.30089

       F
     VALUE

    6.07244

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

     SOURCE OF VARIATION                          DEGREE OF
                                                   FREEDOM

DUE TO REGRESSION...............                      1
 DEVIATION ABOUT REGRESSION.....                     41
                          TOTAL....                  42
```

GRAPH SCALE EXTENDS FROM -1600.0000 TO 34400.0000

X - FLOW (cfs)
Y - NH3-N2 lbs/day
0.0
4000.000
8000.000
12000.000
16000.000
20000.000
24000.000
28000.000
32000.000
36000.000
0.0
2500.000
5000.000
7500.000
10000.000
12500.000
15000.000
17500.000
20000.000
22500.000
25000.000
OP

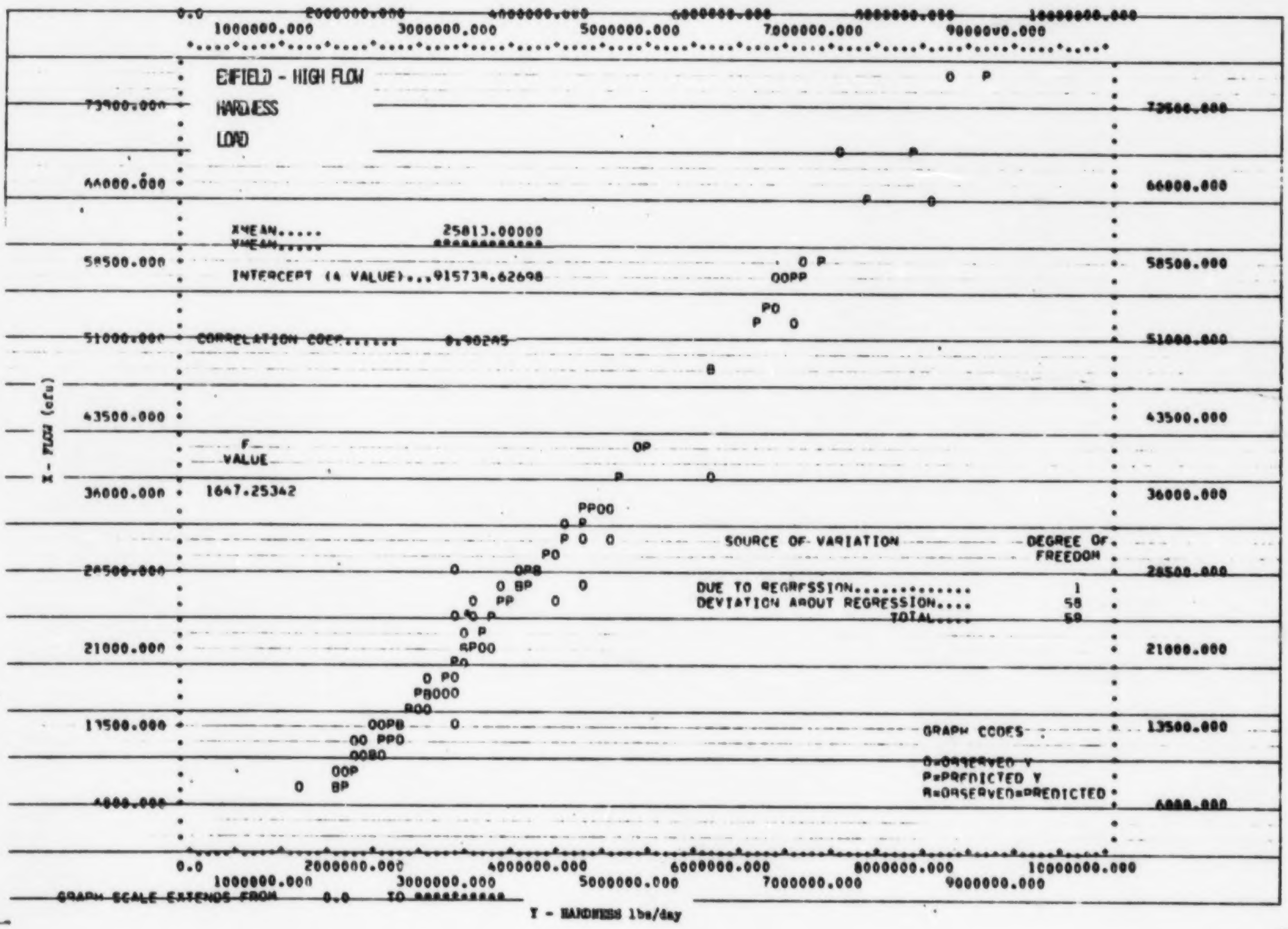

PLOT OF OBSERVED AND PREDICTED VALUES.
ENFIELD - HIGH FLOW
PHOSPHATES
LOAD
0.0
20000.000
40000.000
60000.000
80000.000
100000.000
120000.000
140000.000
160000.000
180000.000
73500.000
66000.000
58500.000
51000.000
43500.000
36000.000
28500.000
21000.000
13500.000
6000.000
X - FLOW (cfs)
Y - PHOSPHATES lbs/day
XMEAN.....
YMEAN.....
INTERCEPT (A VALUE)...
CORRELATION COEFF.......
F
VALUE
79.55436
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION...............
DEVIATION ABOUT REGRESSION.....
TOTAL.....
1
57
O
P
GRAPH SCALE EXTENDS FROM ********** TO **********

PLOT OF OBSERVED AND PREDICTED VALUES.



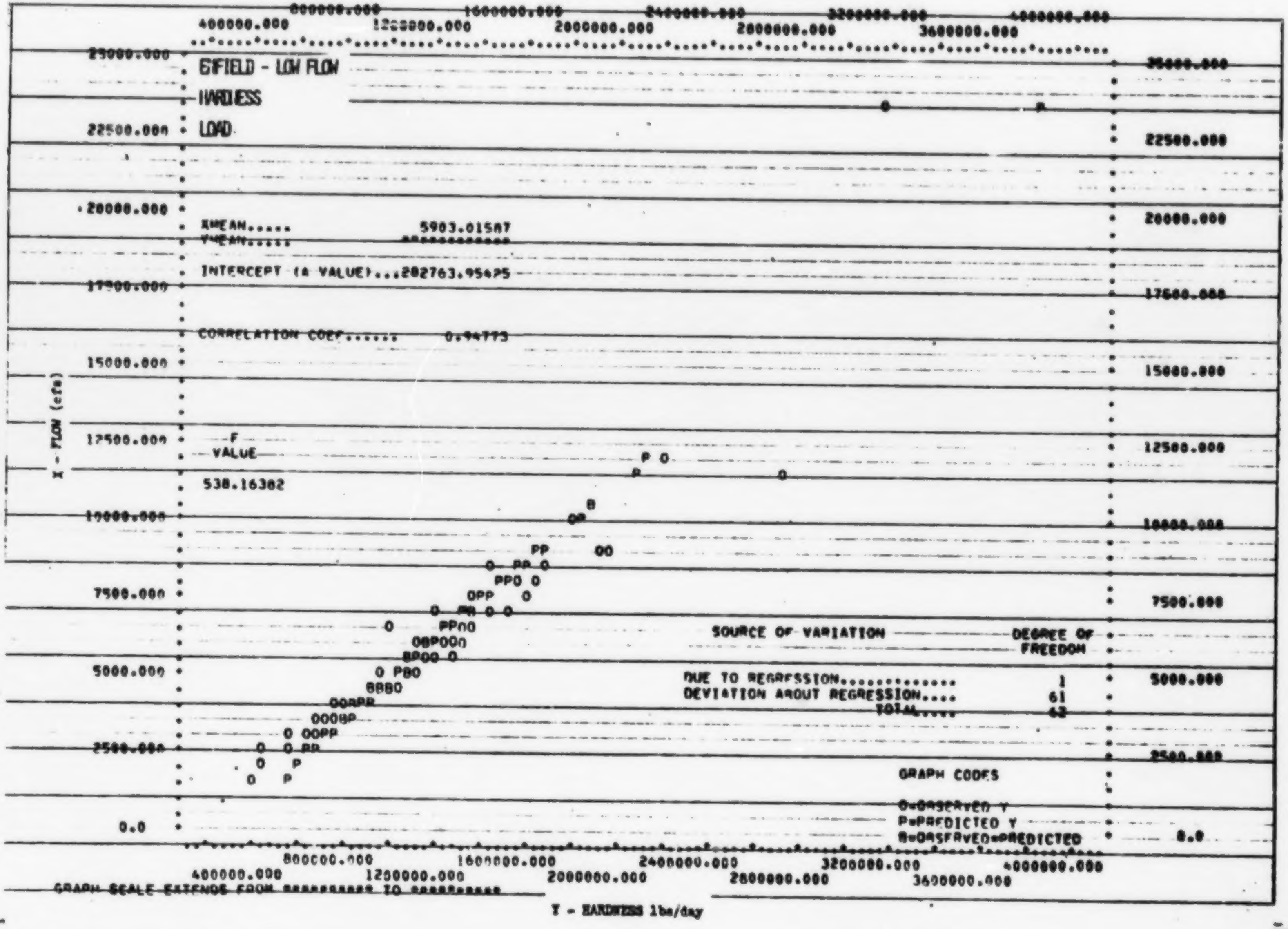
```
ENFIELD - LOW FLOW
PHOSPHATES
LOAD

XMEAN......              5491.91547
YMEAN......             11519.14286

INTERCEPT (A VALUE)...   4303.13659

CORRELATION COEF.......     0.27932

                 F
               VALUE

              5.15794

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

        SOURCE OF VARIATION                    DEGREE OF
                                                FREEDOM

DUE TO REGRESSION..................                1
 DEVIATION ABOUT REGRESSION.....                  61
                          TOTAL.....              62

GRAPH SCALE EXTENDS FROM   300.0000 TO 30300.0000
```

PLOT OF OBSERVED AND PREDICTED VALUES.



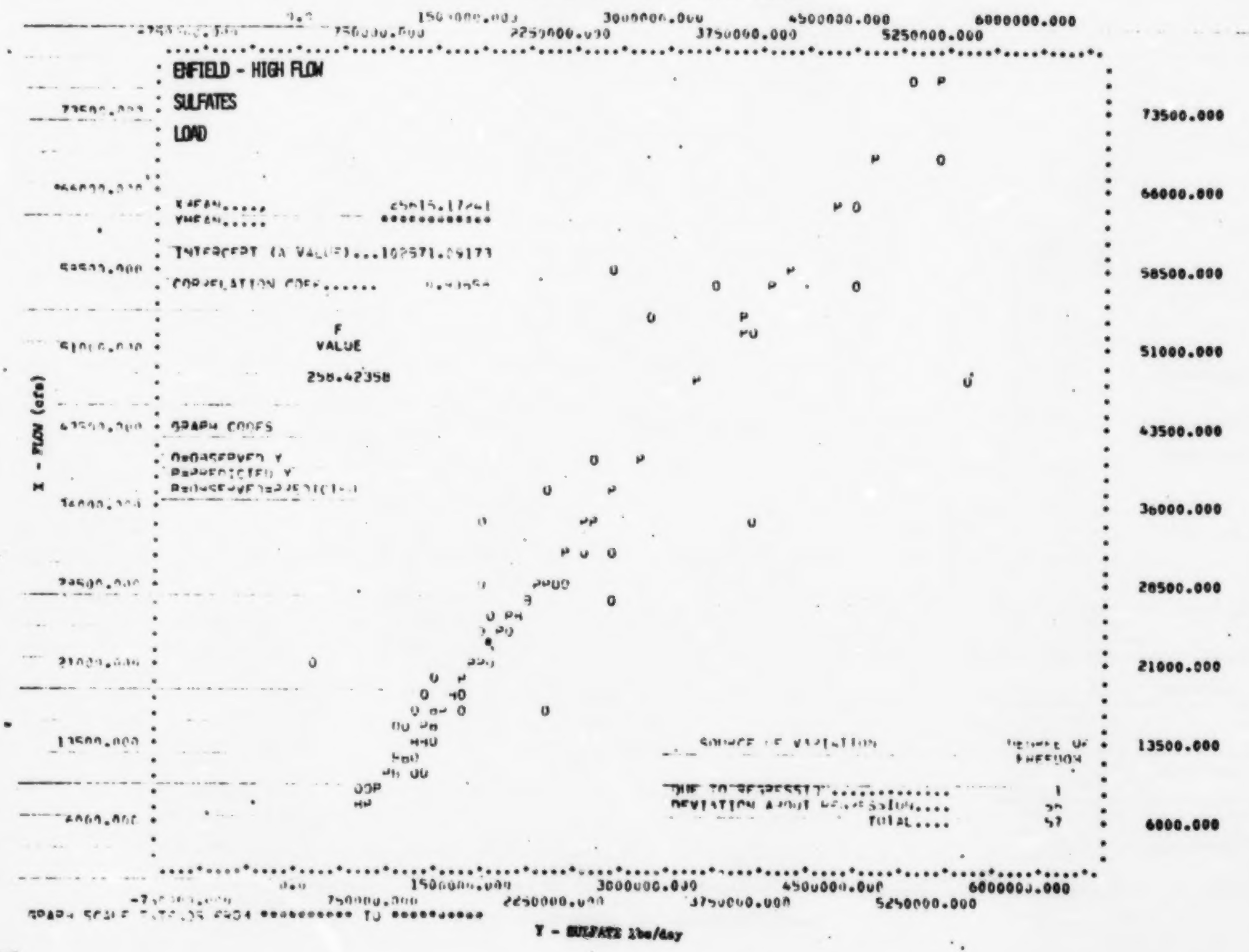
```
XMEAN.....                 25813.00000
YMEAN.....                 [illegible]
INTERCEPT (A VALUE)...915738.62698
CORRELATION COEF.......    0.90285
F
VALUE
1647.25342

SOURCE OF VARIATION                       DEGREE OF
                                          FREEDOM
DUE TO REGRESSION..............               1
DEVIATION ABOUT REGRESSION....               58
                       TOTAL....             59

GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM    0.0    TO [illegible]
```

PLOT OF OBSERVED AND PREDICTED VALUES.



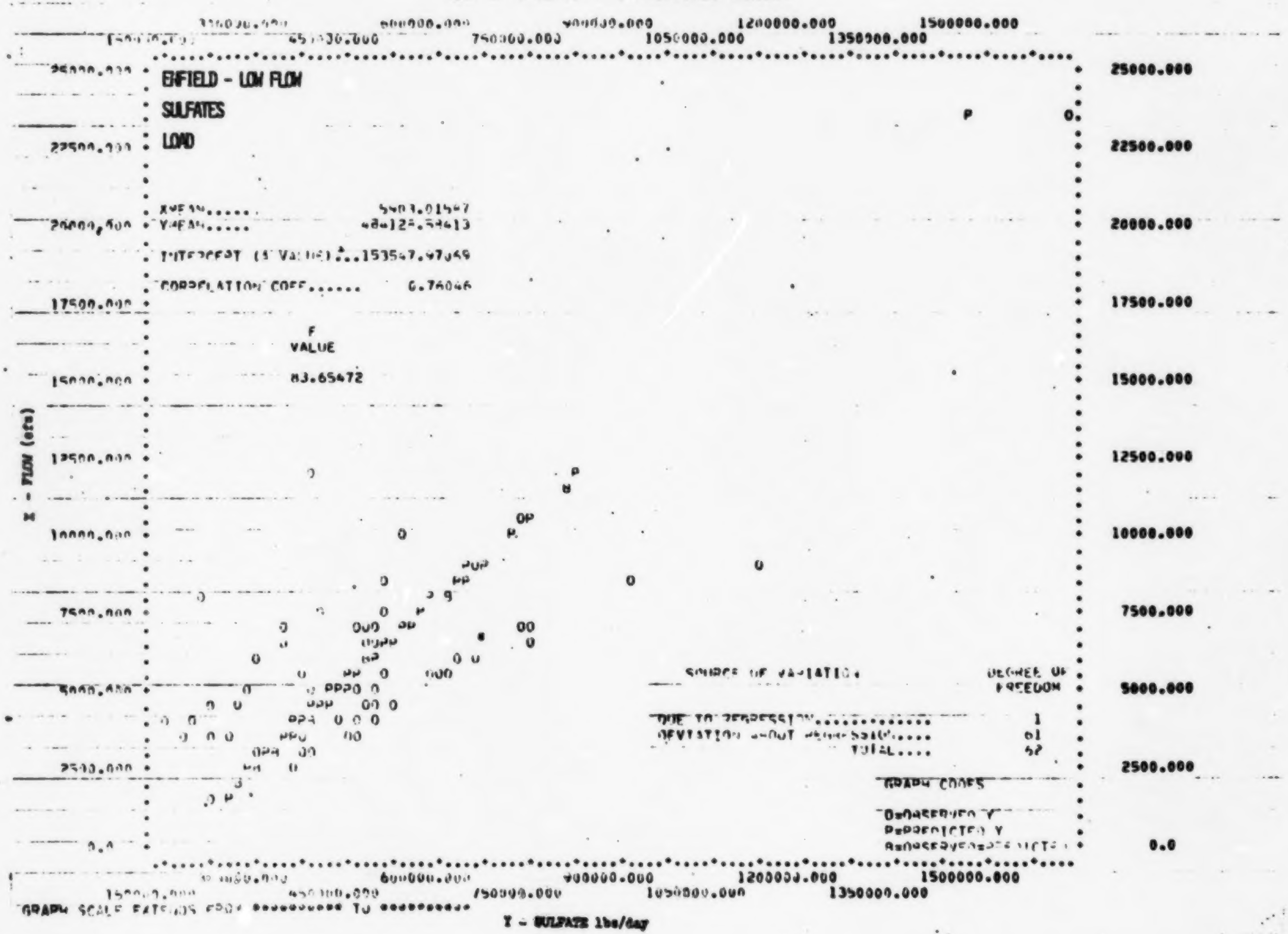
```
XMEAN.....             5903.01587
YMEAN.....           ************
INTERCEPT (A VALUE)...202763.95425
CORRELATION COEF......     0.94773

F
VALUE
538.16302

SOURCE OF VARIATION                      DEGREE OF
                                          FREEDOM
DUE TO REGRESSION................            1
DEVIATION ABOUT REGRESSION....              61
                        TOTAL.....          62

GRAPH SCALE EXTENDS FROM ********** TO **********
```

PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....        25615.17241
YMEAN.....        *************

INTERCEPT (A VALUE)...102571.09173

CORRELATION COEF.......     [illegible]

           F
         VALUE

       258.42358

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

SOURCE OF VARIATION                     DEGREE OF
                                         FREEDOM

DUE TO REGRESSION..............              1
DEVIATION ABOUT REGRESSION....              56
                    TOTAL....               57

GRAPH SCALE RATIOS FROM ********** TO **********
```

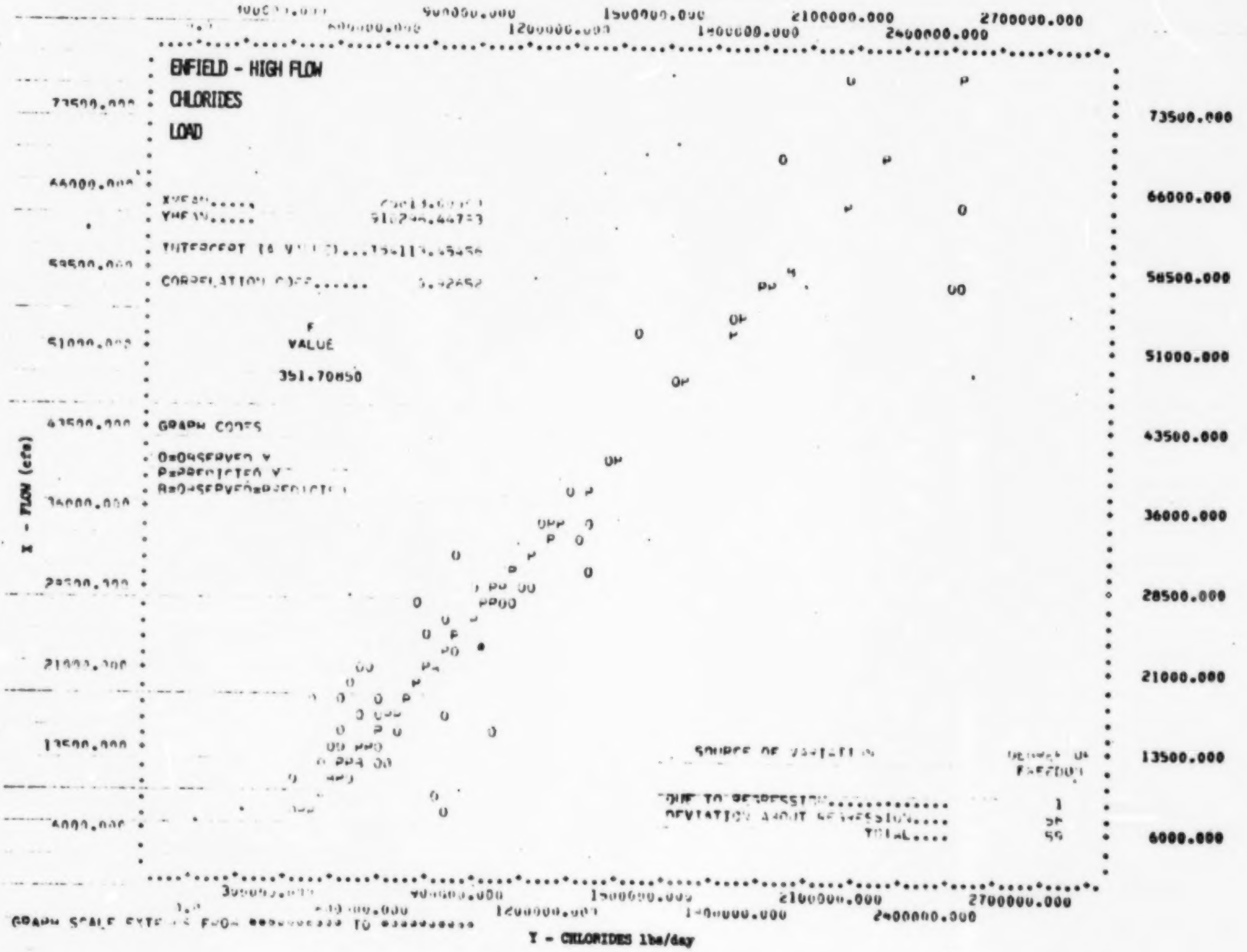
PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN......                 5403.01547
YMEAN......               484125.54413
INTERCEPT (Y VALUE)....153547.47049
CORRELATION COEFF......      0.76046

          F
        VALUE
       83.65472

SOURCE OF VARIATION                         DEGREE OF
                                             FREEDOM
DUE TO REGRESSION...............                1
DEVIATION ABOUT REGRESSION.....                61
                         TOTAL....              62

                     GRAPH CODES

                     O=OBSERVED Y
                     P=PREDICTED Y
                     B=OBSERVED=PREDICTED
```

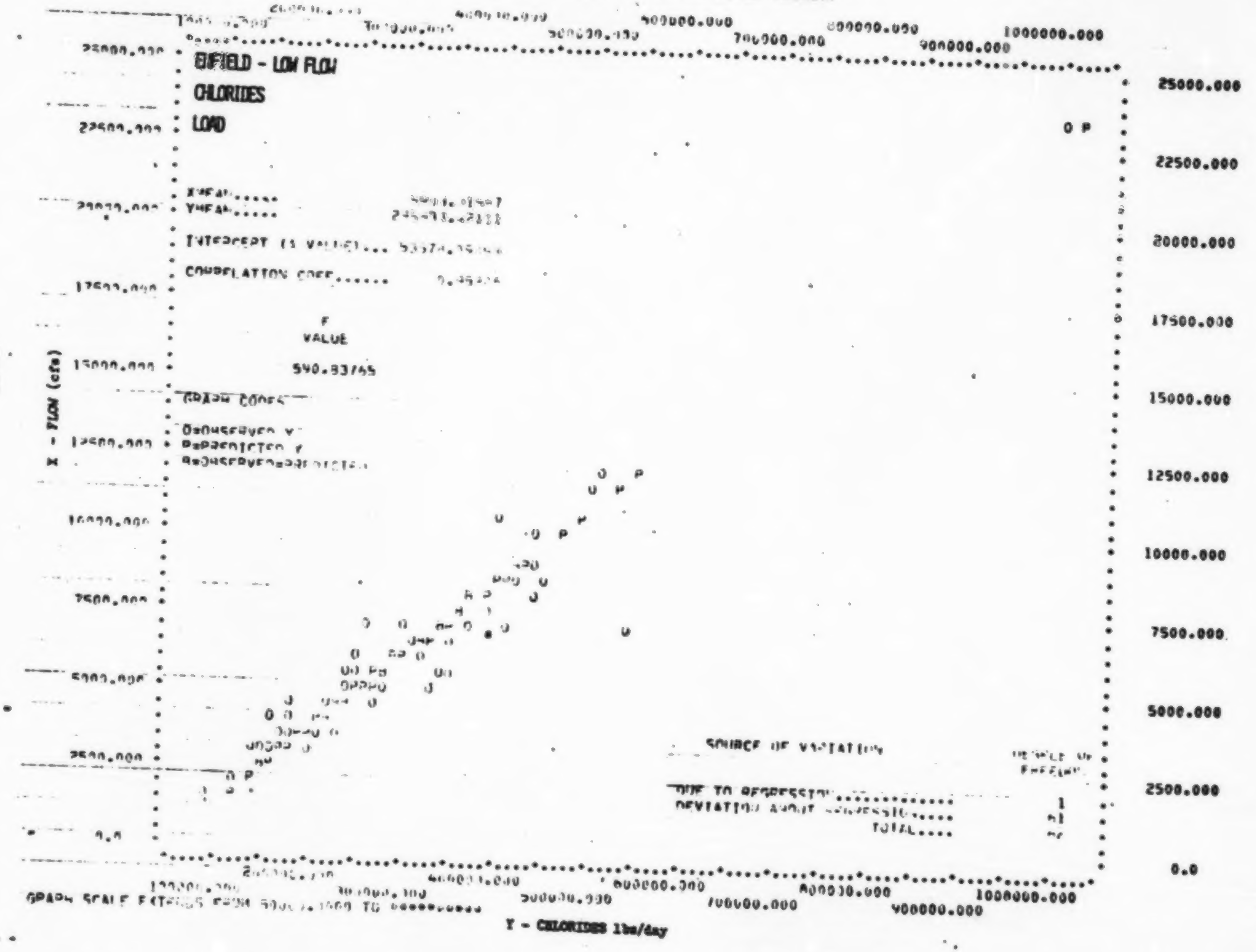
GRAPH SCALE RATIOS FROM ********** TO **********

PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....
YMEAN.....                 91?2??.447?3
INTERCEPT (A VALUE)...1?411?.?5456
CORRELATION COEF......       ?.92652

              F
            VALUE

          351.70850

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

SOURCE OF VARIATION                    DEGREES OF
                                       FREEDOM

DUE TO REGRESSION...............           1
DEVIATION ABOUT REGRESSION......          58
                       TOTAL....          59

GRAPH SCALE EXTENDS FROM ********** TO **********
```

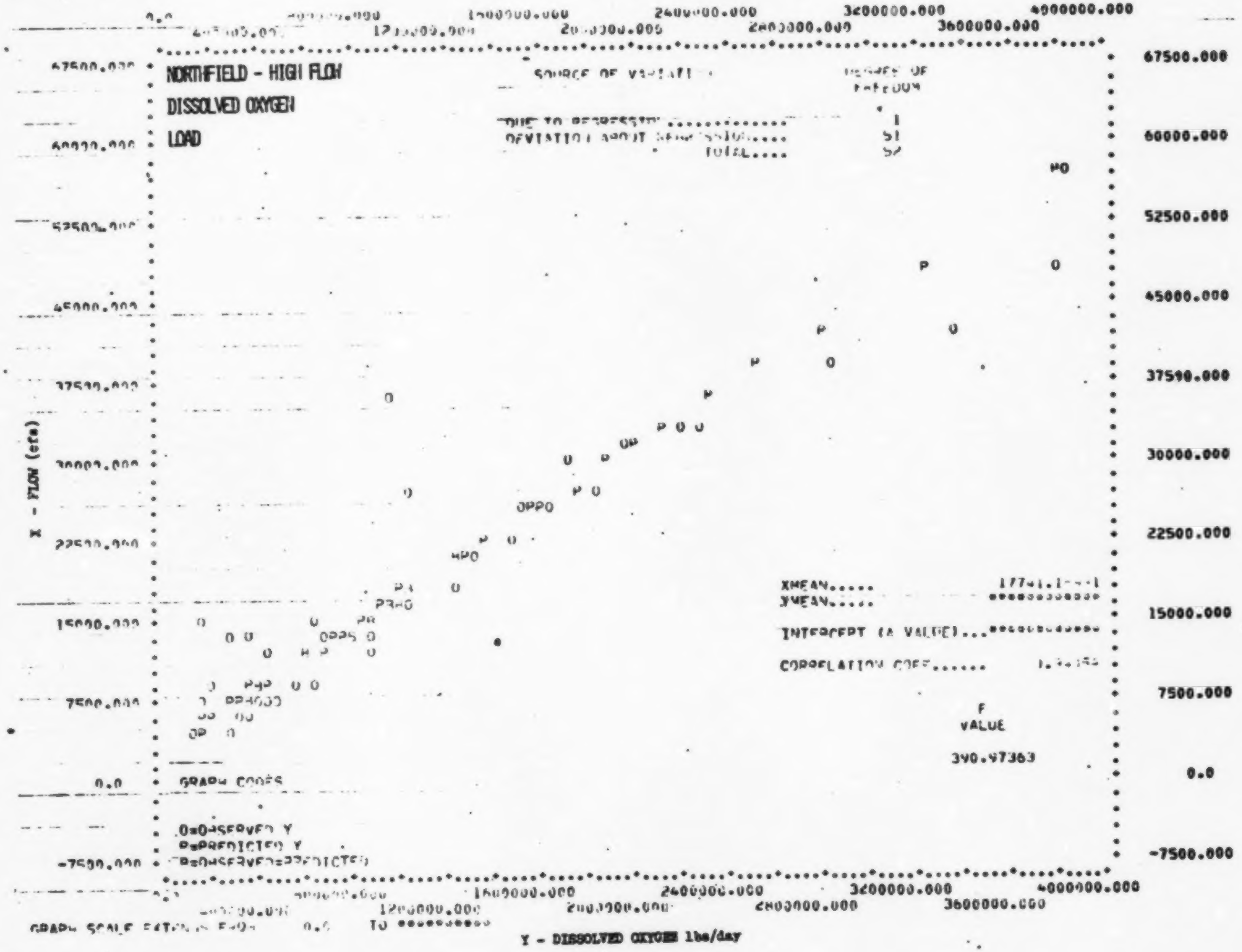
PLOT OF OBSERVED AND PREDICTED VALUES.



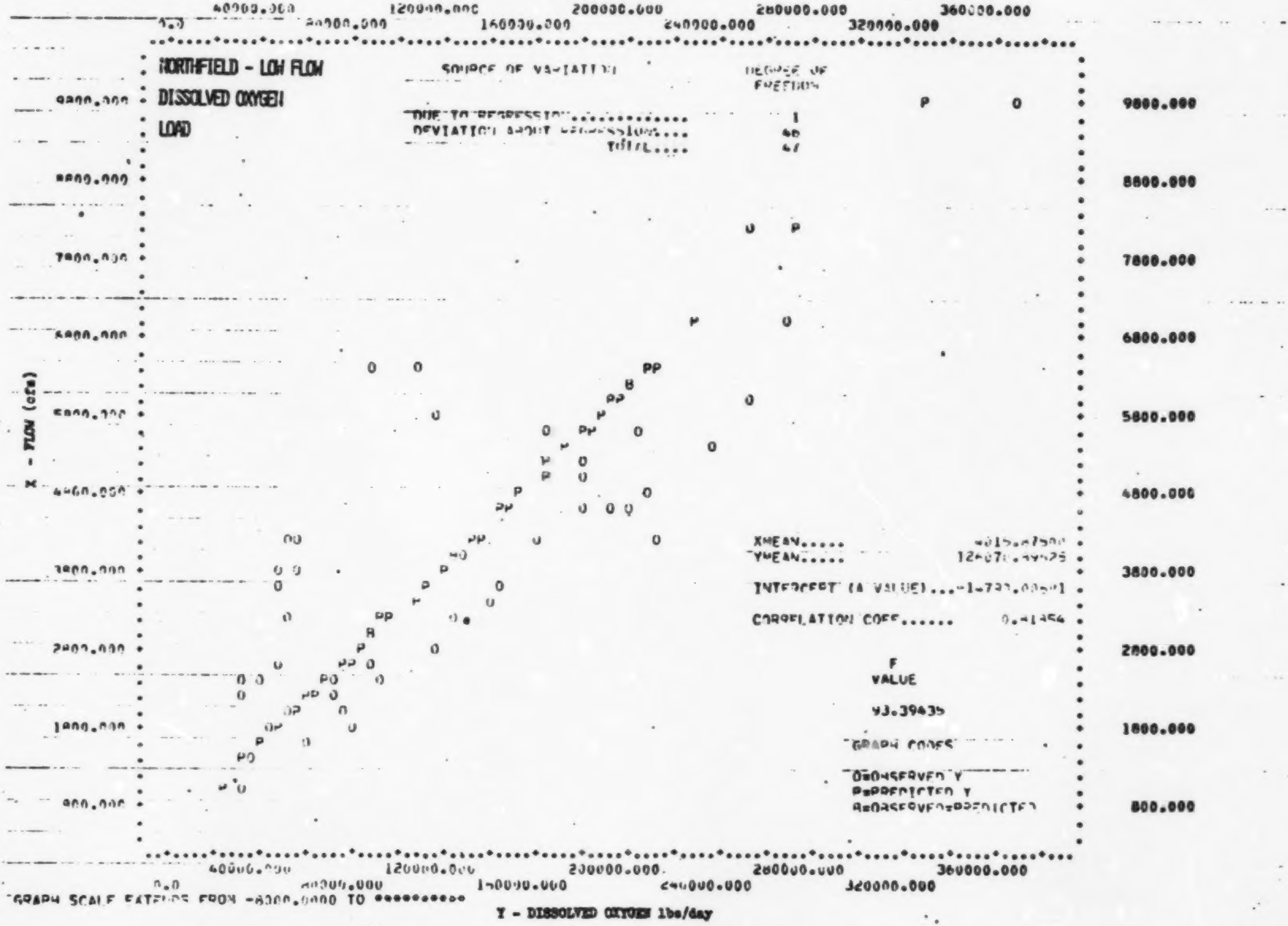
```
XMEAN.....                [illegible]
YMEAN.....                [illegible]

INTERCEPT (Y VALUE)...    [illegible]

CORRELATION COEF......    [illegible]

             F
           VALUE

         540.83765

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

       SOURCE OF VARIATION                    DEGREES OF
                                              FREEDOM

DUE TO REGRESSION...............                  1
DEVIATION ABOUT REGRESSION......                 61
                      TOTAL.....                 62
```

GRAPH SCALE EXTENDS FROM [illegible] TO [illegible]

PLOT OF OBSERVED AND PREDICTED VALUES.

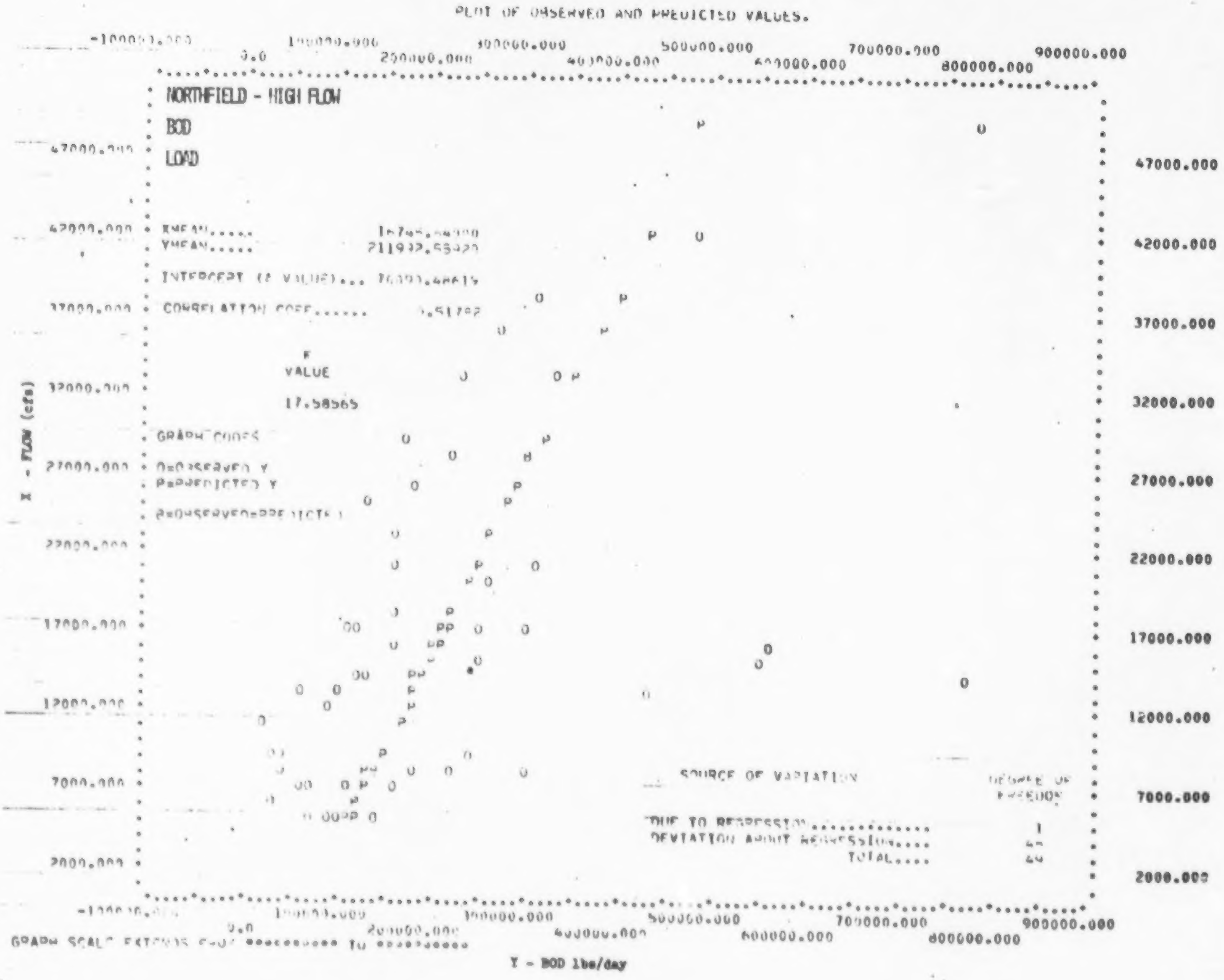


PLOT OF OBSERVED AND PREDICTED VALUES.

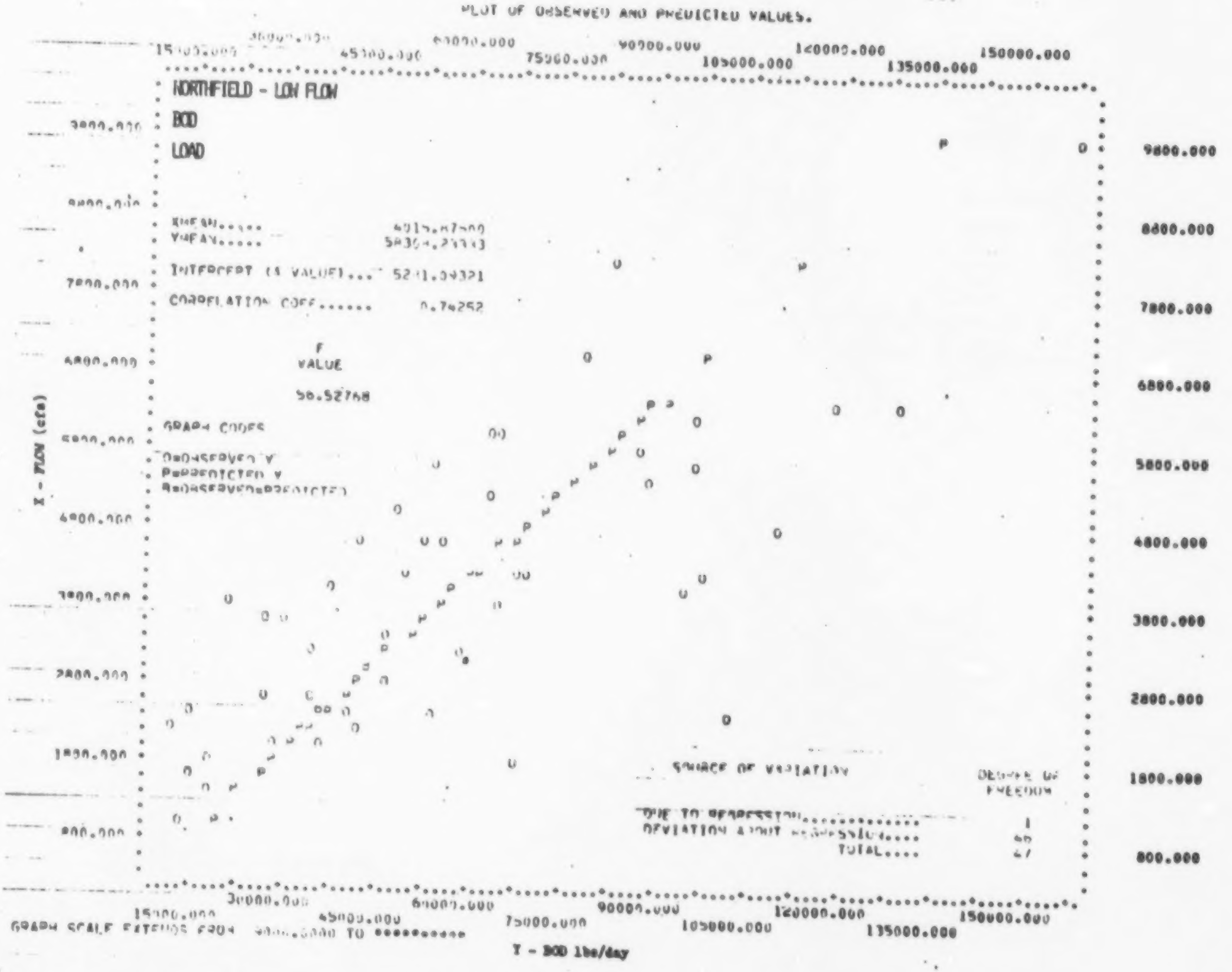


```
SOURCE OF VARIATION                         DEGREE OF
                                             FREEDOM

DUE TO REGRESSION...............                1
DEVIATION ABOUT REGRESSION......               46
                           TOTAL....           47

XMEAN.....                        4015.87500
YMEAN.....                      126070.44625

INTERCEPT (A VALUE)...-14733.00501

CORRELATION COEF.......            0.81854

            F
          VALUE

        93.39435

       GRAPH CODES

        O=OBSERVED Y
        P=PREDICTED Y
        B=OBSERVED=PREDICTED
```

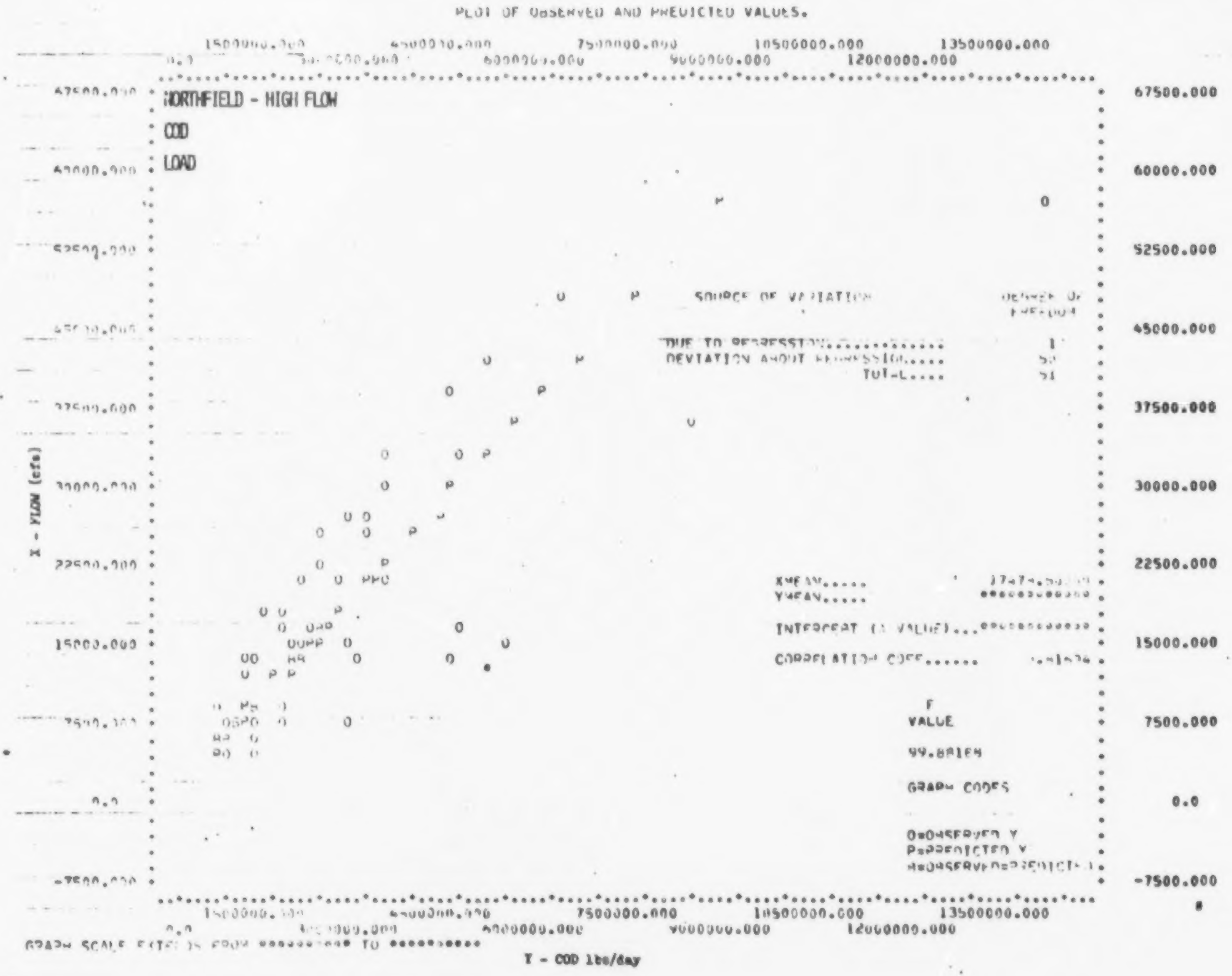
GRAPH SCALE EXTENDS FROM -8000.0000 TO *********



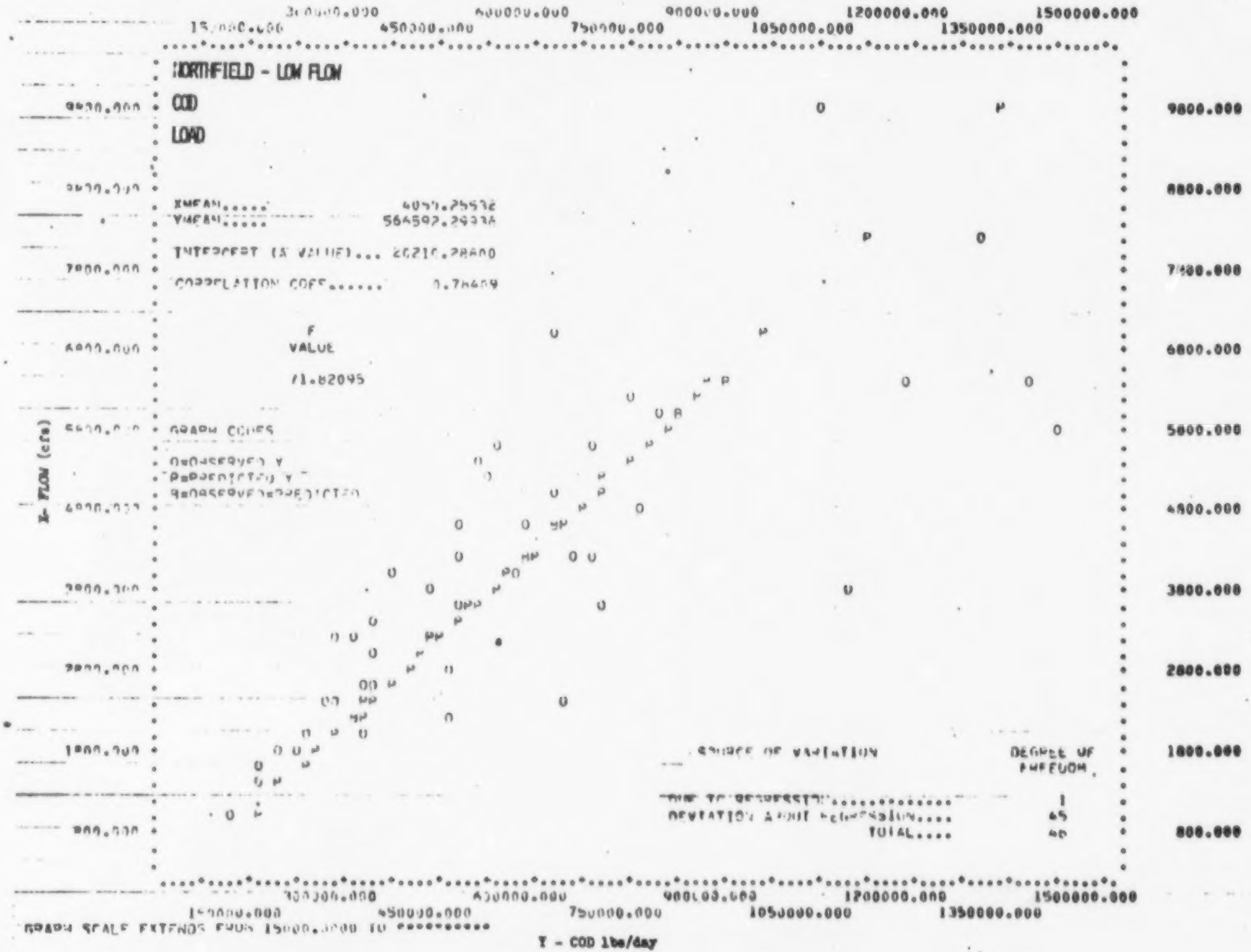
```
XMEAN.....                16745.44900
YMEAN.....               211932.55429

INTERCEPT (Y VALUE)... 76093.48615

CORRELATION COEF......      0.51782

          F
        VALUE

       17.58565

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

                    SOURCE OF VARIATION                  DEGREE OF
                                                          FREEDOM

              DUE TO REGRESSION..............                1
              DEVIATION ABOUT REGRESSION....                48
                                   TOTAL....                49

GRAPH SCALE EXTENDS FROM ********** TO **********
```



```
XMEAN.....              4915.87500
YMEAN.....             58364.29333

INTERCEPT (A VALUE)...  5241.04321

CORRELATION COEFF.......   0.74252

           F
         VALUE

        56.52768

SOURCE OF VARIATION                          DEGREE OF
                                              FREEDOM

DUE TO REGRESSION.................               1
DEVIATION ABOUT REGRESSION.....                 46
                          TOTAL....             47
```


PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - HIGH FLOW
COD
LOAD
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION............ 1
DEVIATION ABOUT REGRESSION..... 50
TOTAL..... 51
XMEAN.....
YMEAN.....
INTERCEPT (A VALUE)...
CORRELATION COEF......
F VALUE
99.88189
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
H=OBSERVED=PREDICTED
67500.000
60000.000
52500.000
45000.000
37500.000
30000.000
22500.000
15000.000
7500.000
0.0
-7500.000
0.0
1500000.000
3000000.000
4500000.000
6000000.000
7500000.000
9000000.000
10500000.000
12000000.000
13500000.000
X - FLOW (cfs)
Y - COD lbs/day
GRAPH SCALE EXTENDS FROM ********** TO **********

PLOT OF OBSERVED AND PREDICTED VALUES.



NORTHFIELD - LOW FLOW

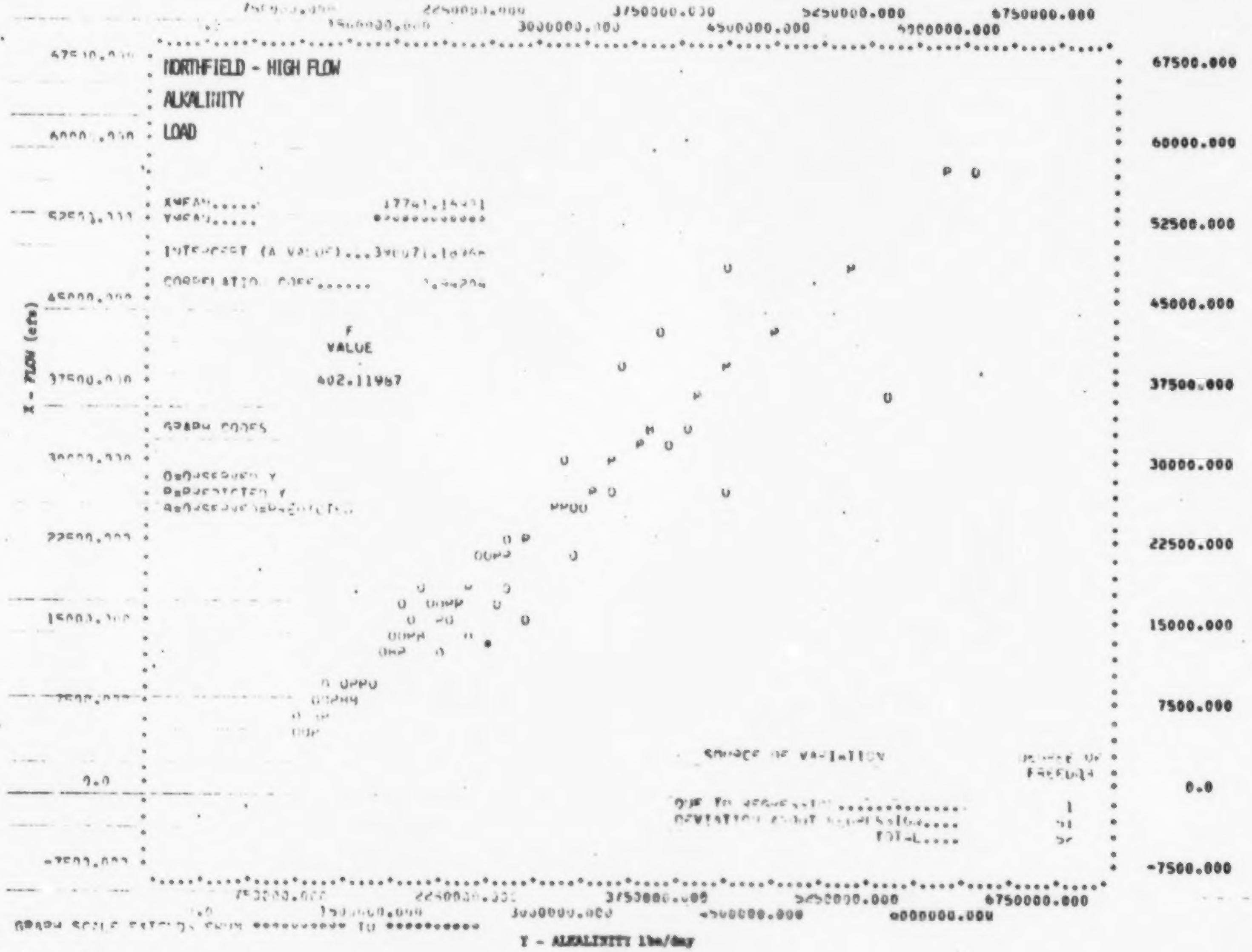
COD

LOAD

```
XMEAN.....                  4057.25532
YMEAN.....                564592.29336

INTERCEPT (A VALUE)...     26210.28600

CORRELATION COFF......         0.78409

          F
        VALUE

       71.82095

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

   SOURCE OF VARIATION                         DEGREE OF
                                               FREEDOM.

DUE TO REGRESSION................                 1
DEVIATION ABOUT REGRESSION.....                  65
                        TOTAL....                66
```

GRAPH SCALE EXTENDS FROM 15000.0000 TO **********

PLOT OF OBSERVED AND PREDICTED VALUES.



NORTHFIELD - HIGH FLOW
ALKALINITY
LOAD

XMEAN...... 17741.15431
YMEAN...... ************

INTERCEPT (A VALUE)...390071.10466

CORRELATION COEF....... 0.94294

F
VALUE
402.11967

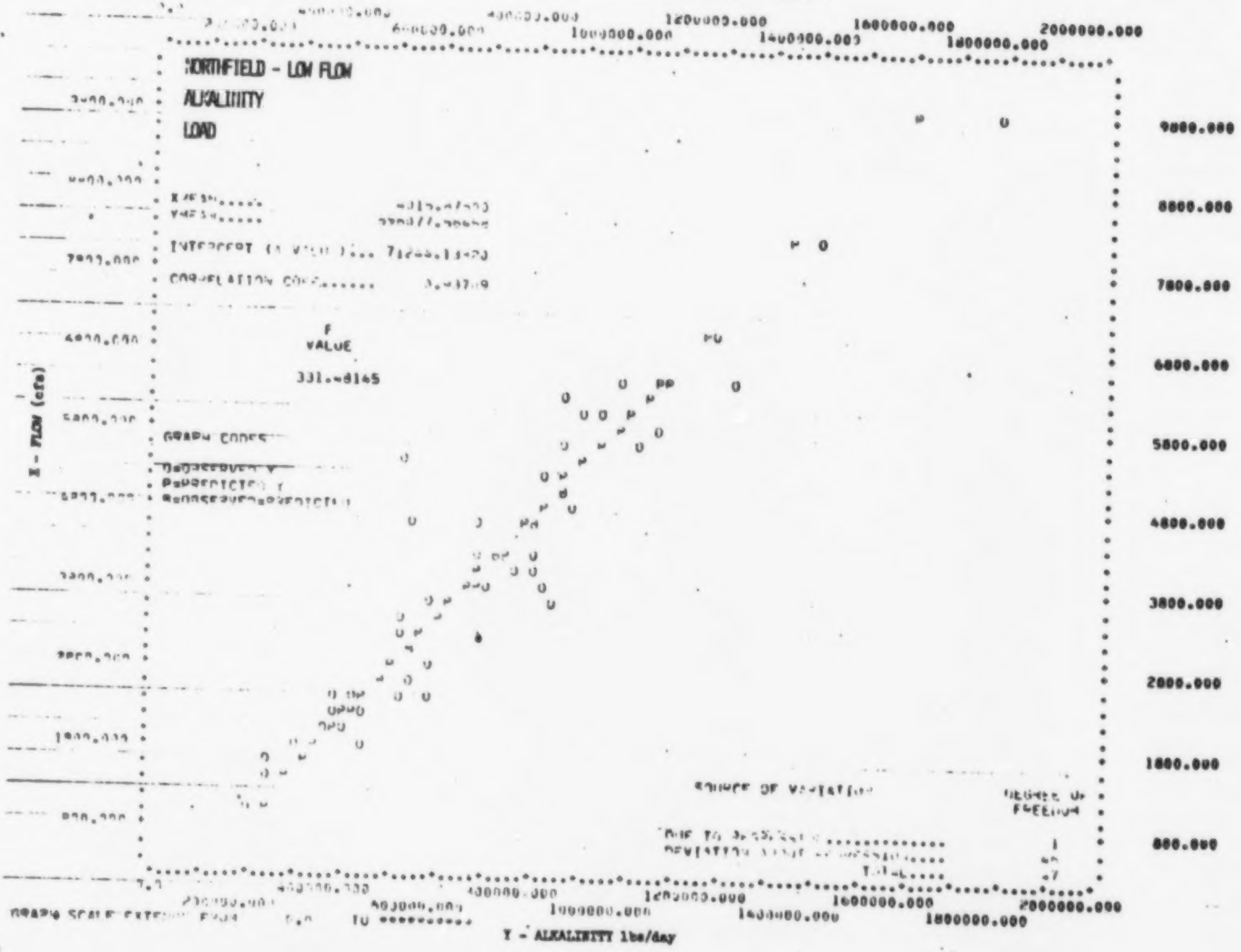
GRAPH CODES

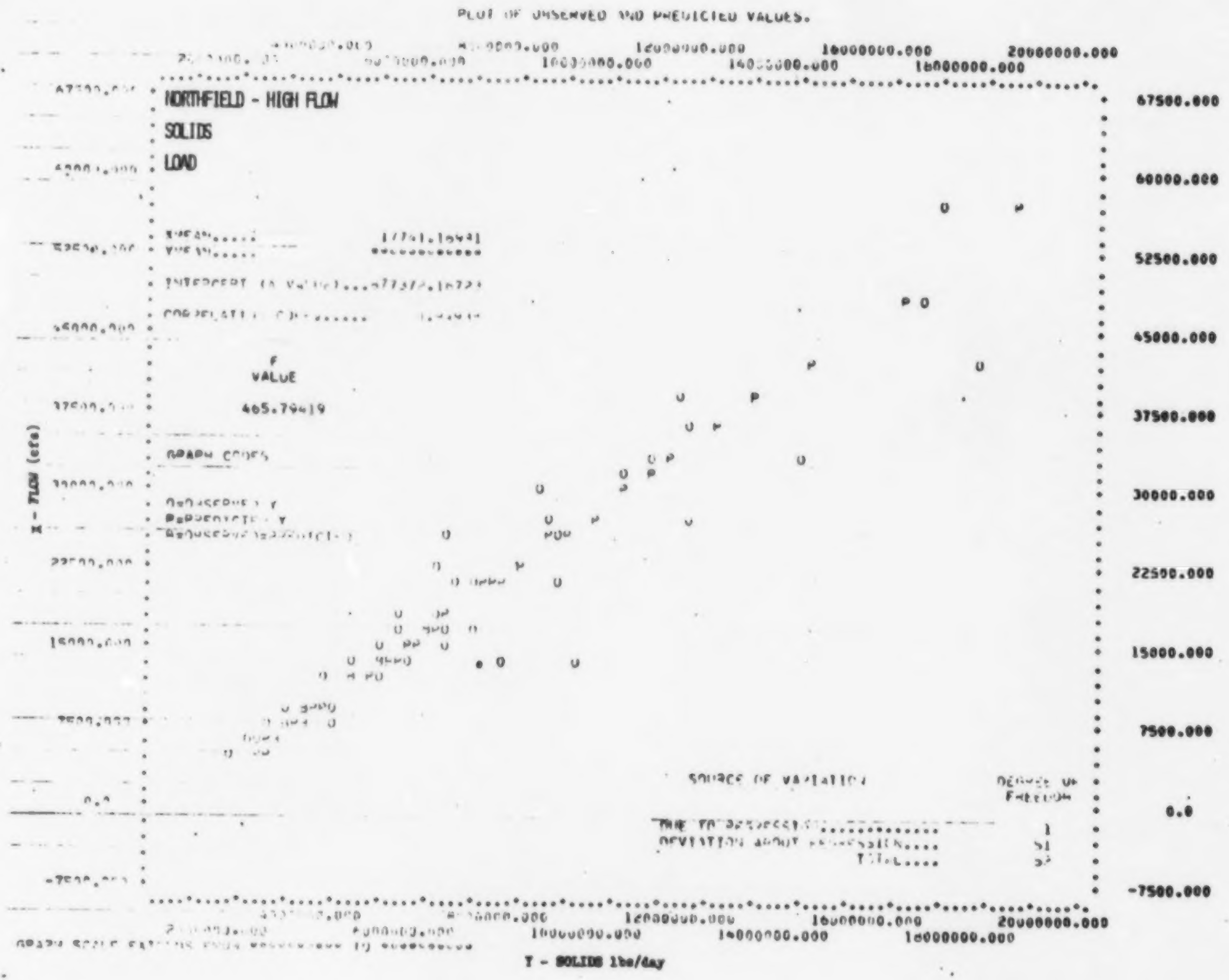
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

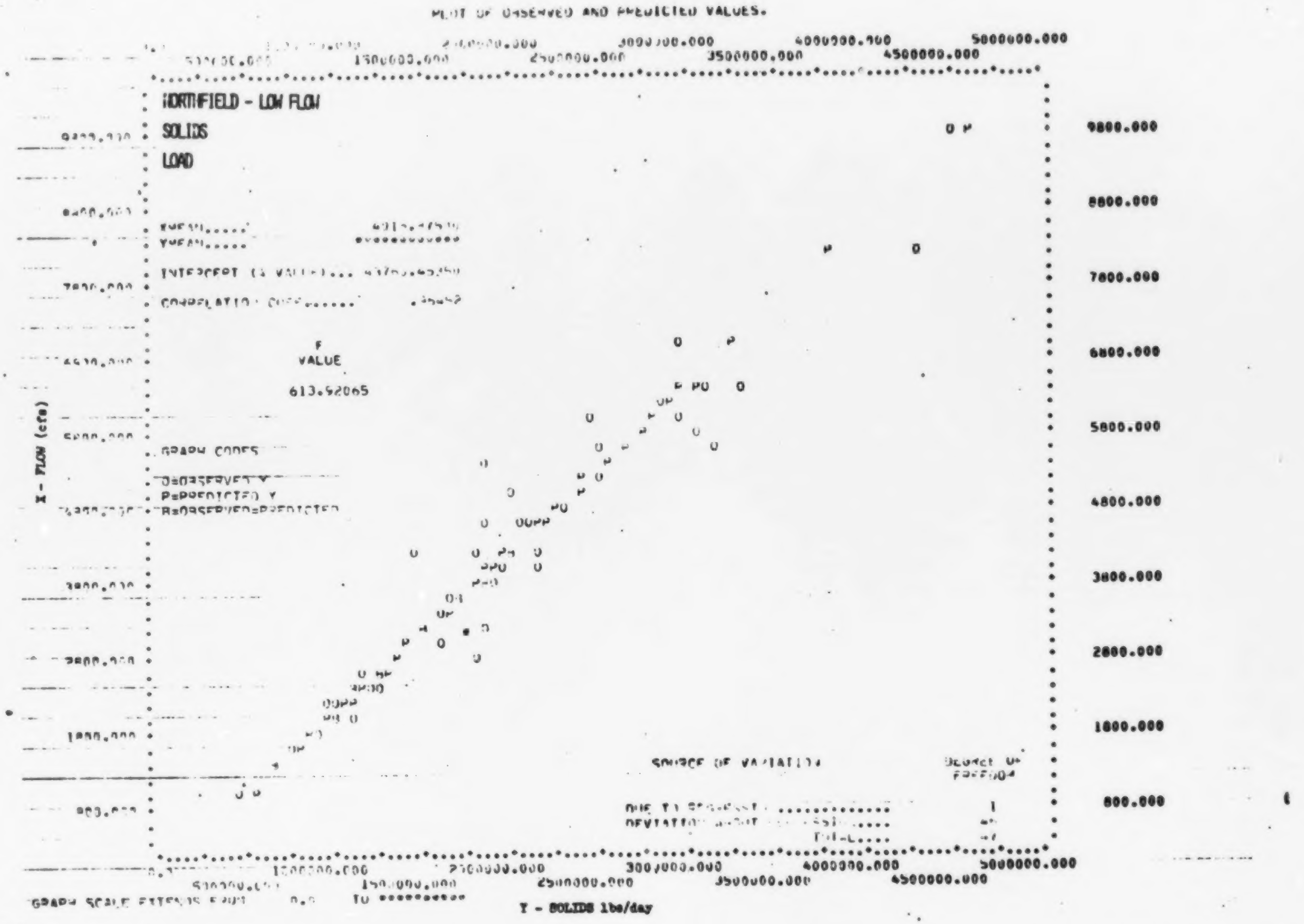
SOURCE OF VARIATION — DEGREE OF FREEDOM
DUE TO REGRESSION............... 1
DEVIATION ABOUT REGRESSION..... 51
TOTAL..... 52

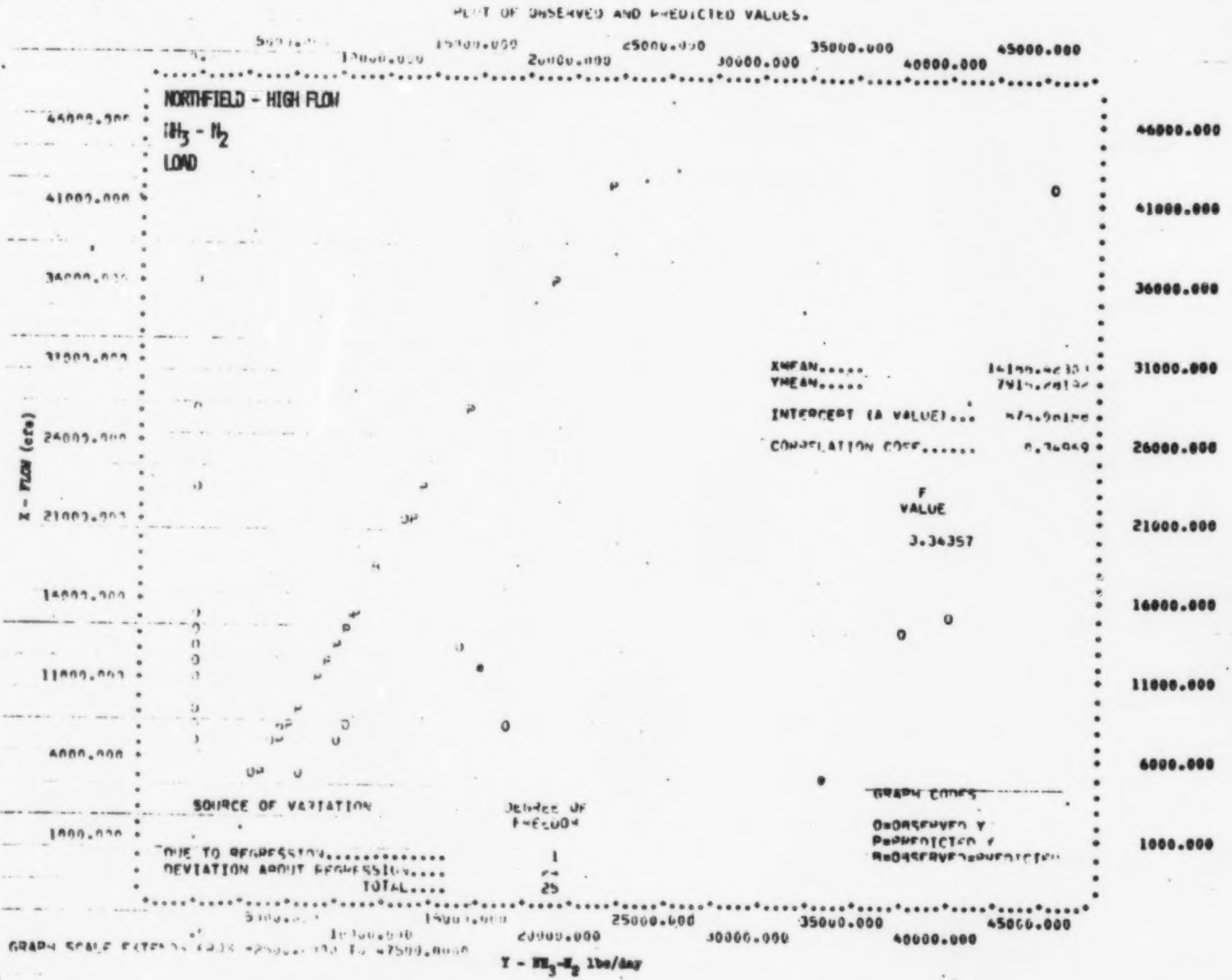
GRAPH SCALE EXTENDS FROM ********** TO **********

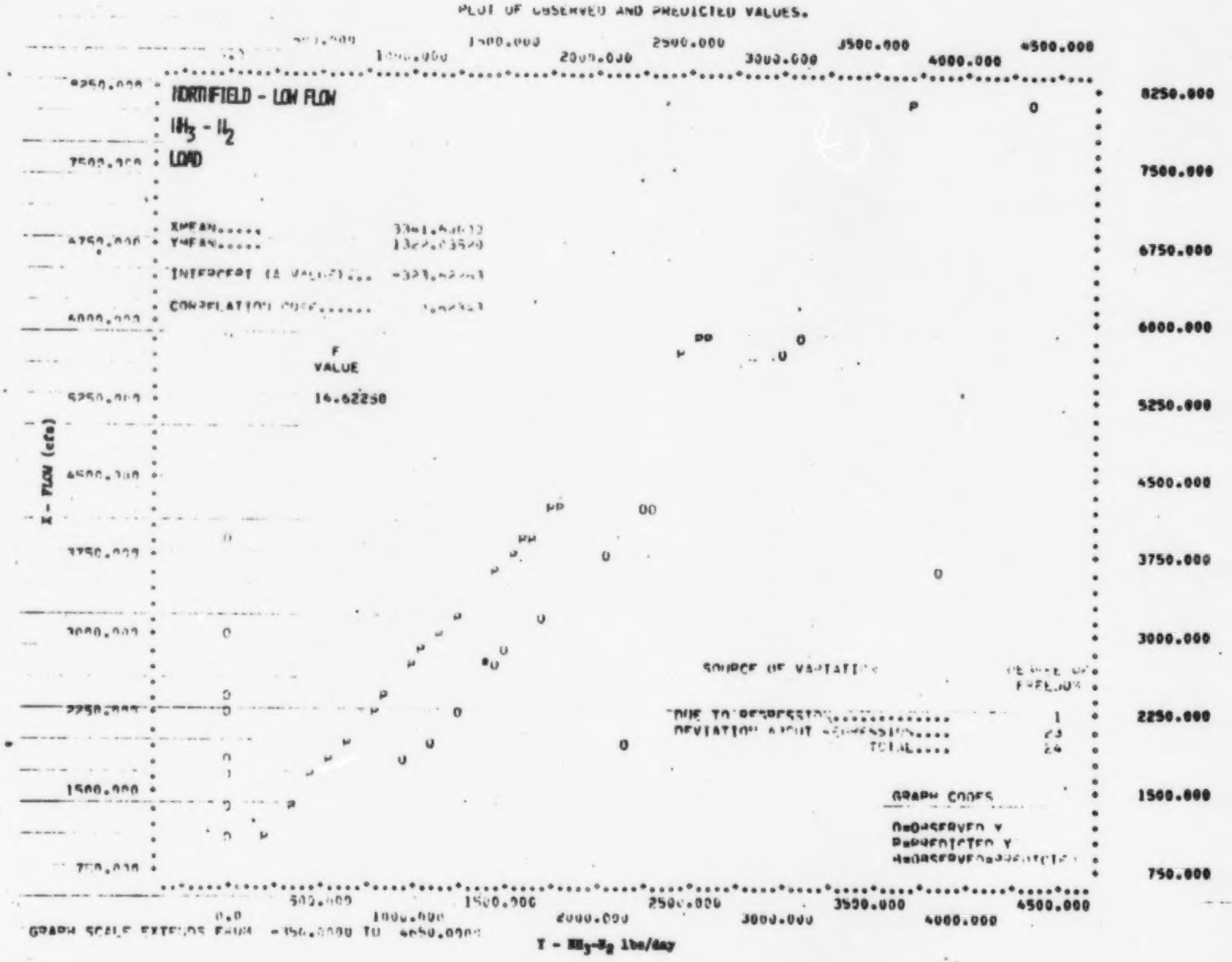
PLOT OF OBSERVED AND PREDICTED VALUES.




PLOT OF OBSERVED AND PREDICTED VALUES.
12000000.000
16000000.000
20000000.000
10000000.000
14000000.000
18000000.000
NORTHFIELD - HIGH FLOW
SOLIDS
LOAD
67500.000
60000.000
52500.000
45000.000
37500.000
30000.000
22500.000
15000.000
7500.000
0.0
-7500.000
INTERCEPT
F
VALUE
465.79419
GRAPH CODES
SOURCE OF VARIATION
DEGREES OF FREEDOM
DEVIATION ABOUT REGRESSION....
1
51
X - FLOW (cfs)
Y - SOLIDS lbs/day

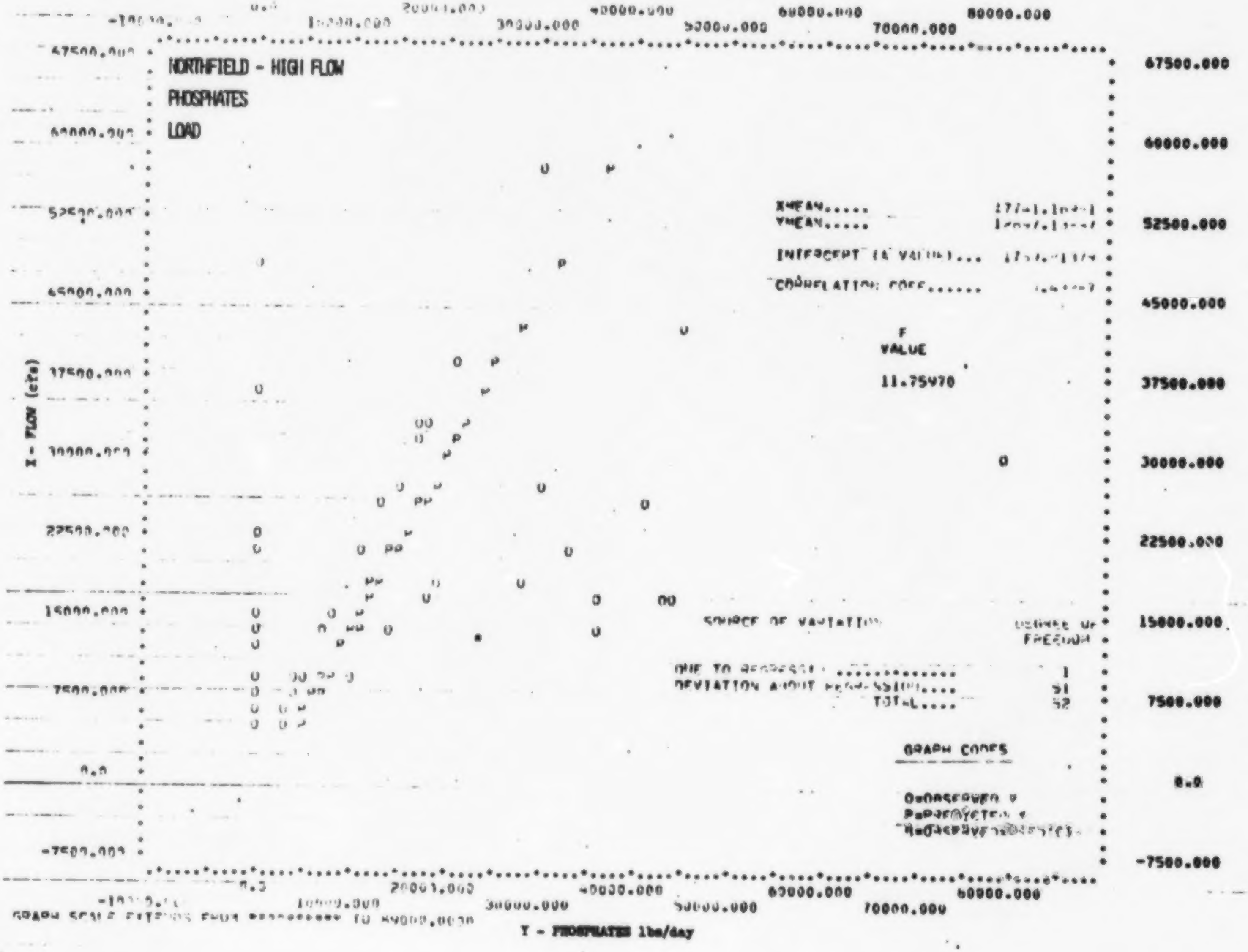

PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - LOW FLOW
SOLIDS
LOAD
XMEAN.....
YMEAN.....
INTERCEPT (A VALUE)...
CORRELATION COEF.......
F
VALUE
613.92065
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION
DEVIATION ABOUT REGRESSION
TOTAL
1
500000.000
1000000.000
1500000.000
2000000.000
2500000.000
3000000.000
3500000.000
4000000.000
4500000.000
5000000.000
800.000
1800.000
2800.000
3800.000
4800.000
5800.000
6800.000
7800.000
8800.000
9800.000
X - FLOW (cfs)
Y - SOLIDS lbs/day
GRAPH SCALE EXTENDS FROM 0.0 TO

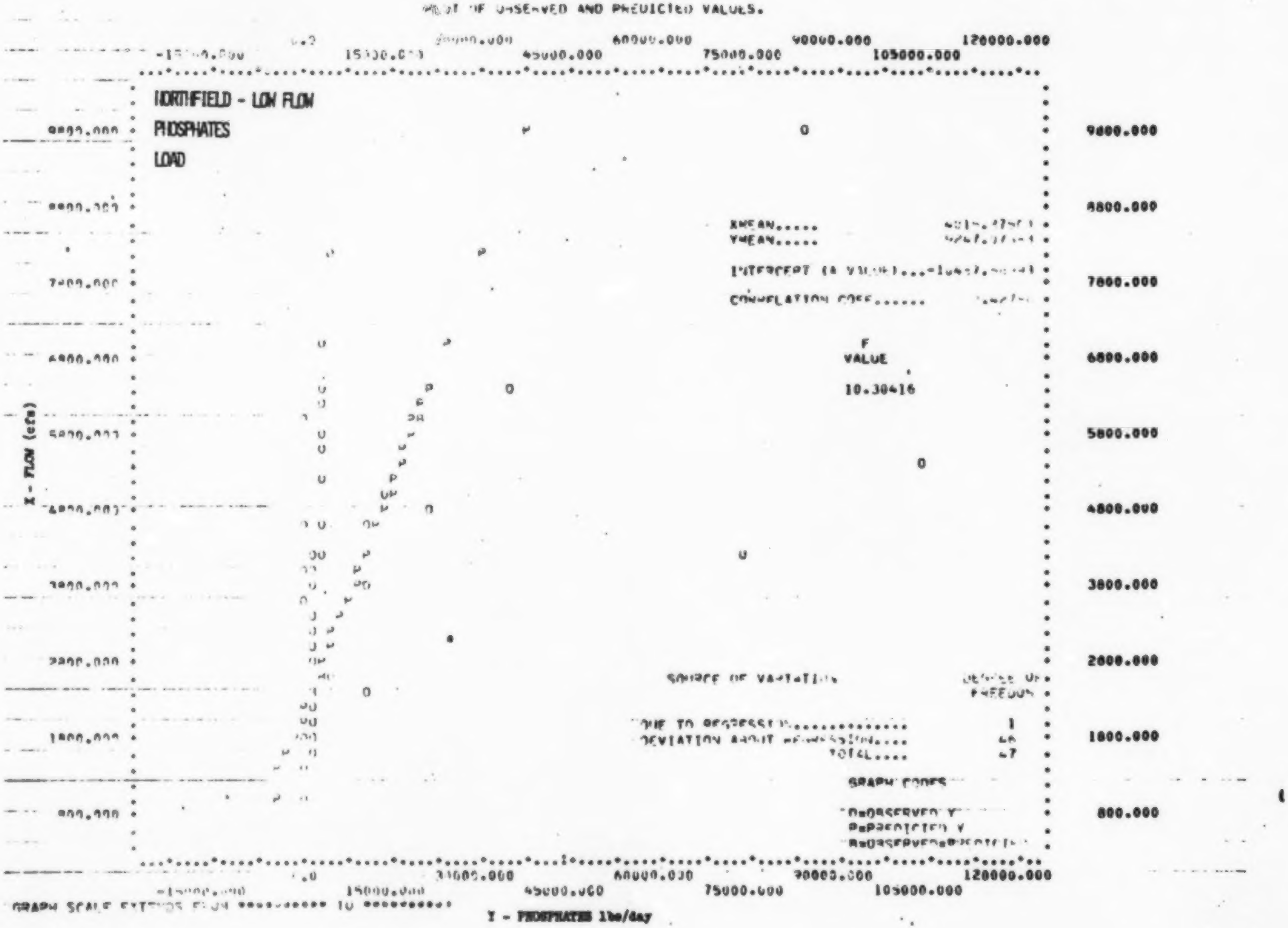

PLOT OF OBSERVED AND PREDICTED VALUES.
5000.000
10000.000
15000.000
20000.000
25000.000
30000.000
35000.000
40000.000
45000.000
NORTHFIELD - HIGH FLOW
$NH_3 - N_2$
LOAD
46000.000
41000.000
36000.000
31000.000
26000.000
21000.000
16000.000
11000.000
6000.000
1000.000
X - FLOW (cfs)
Y - NH_3-N_2 lbs/day
XMEAN......
YMEAN......
INTERCEPT (A VALUE)...
CORRELATION COEF.......
0.34049
F
VALUE
3.34357
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION.............
DEVIATION ABOUT REGRESSION....
TOTAL....
1
24
25
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
GRAPH SCALE EXTENDS FROM -2500.000 TO 47500.0000



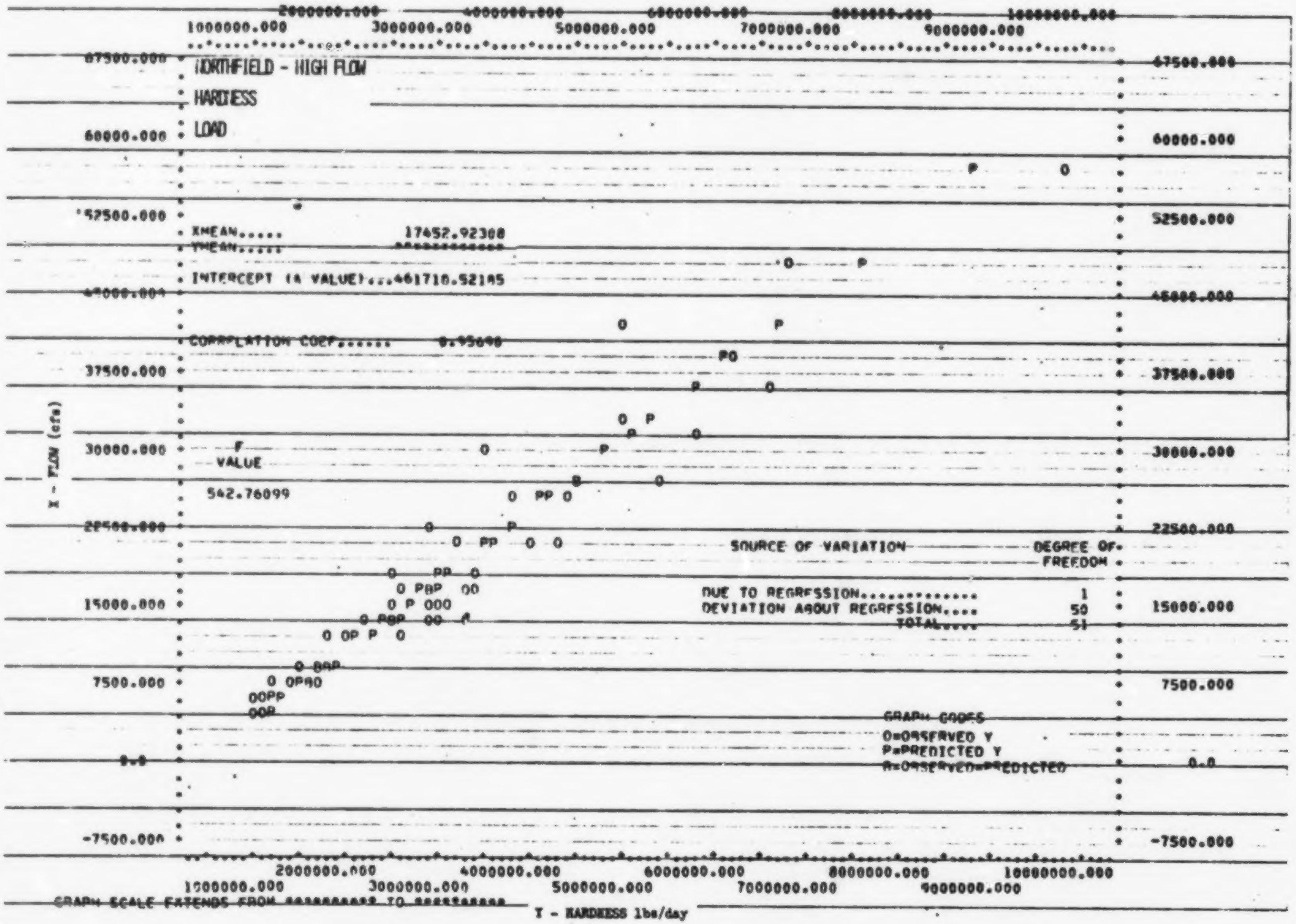
```
NORTHFIELD - LOW FLOW
NH3 - N2
LOAD

XMEAN.....              3341.6[illegible]
YMEAN.....              1322.63520

INTERCEPT (A VALUE)...  -323.6[illegible]

CORRELATION COEF......  .6[illegible]

        F
      VALUE

    14.62250

SOURCE OF VARIATION                         DEGREE OF
                                            FREEDOM

DUE TO REGRESSION.................             1
DEVIATION ABOUT REGRESSION.....               23
                     TOTAL.....               24

                             GRAPH CODES

                             O=OBSERVED Y
                             P=PREDICTED Y
                             *=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM  -150.0000 TO  4650.0000
```

PLOT OF OBSERVED AND PREDICTED VALUES.



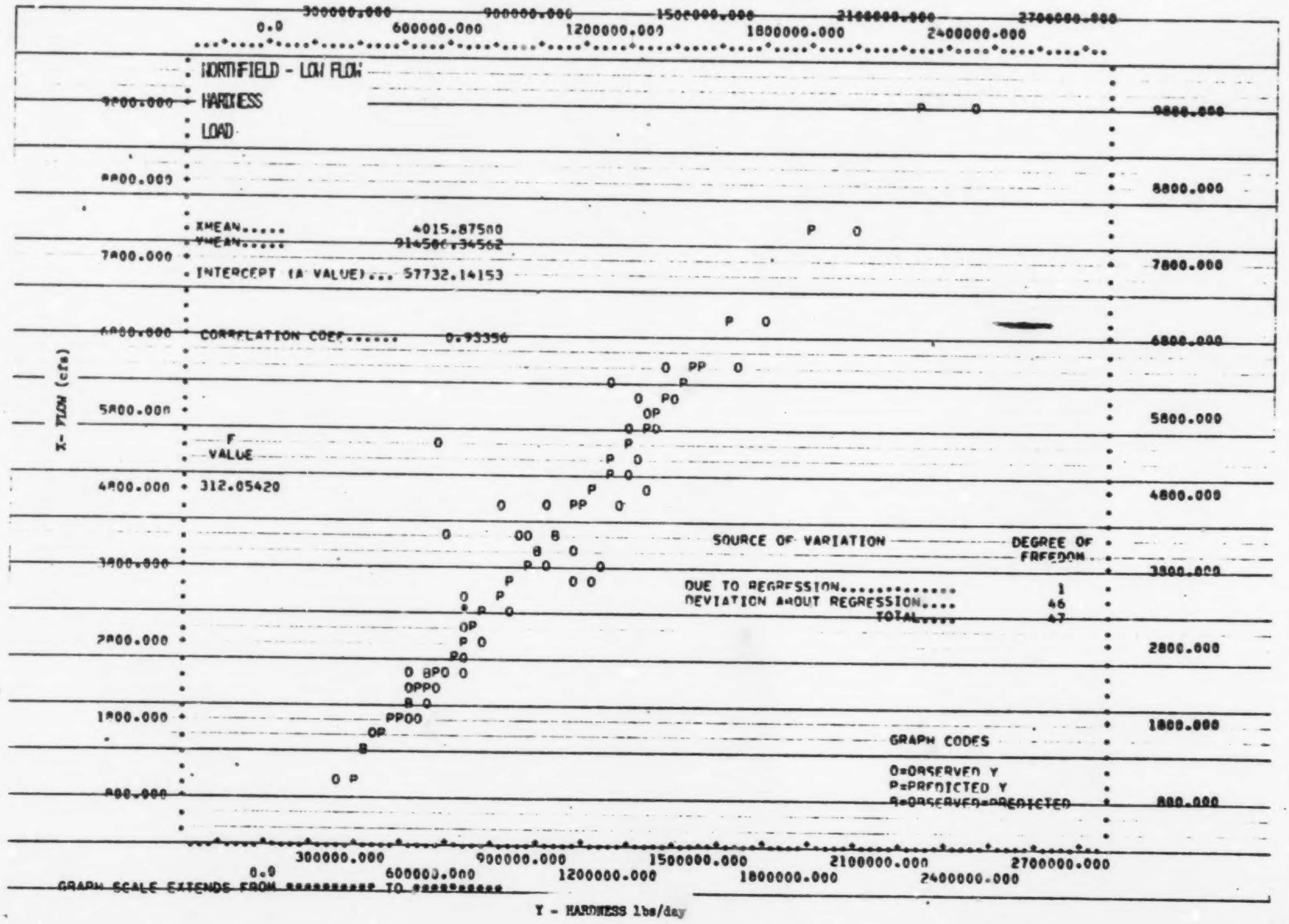

PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - LOW FLOW
PHOSPHATES
LOAD
-15000.000
0.0
15000.000
30000.000
45000.000
60000.000
75000.000
90000.000
105000.000
120000.000
9800.000
8800.000
7800.000
6800.000
5800.000
4800.000
3800.000
2800.000
1800.000
800.000
XMEAN.....
YMEAN.....
INTERCEPT (A VALUE)...
CORRELATION COEF......
F
VALUE
10.30416
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION............
DEVIATION ABOUT REGRESSION....
TOTAL....
1
46
47
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
R=OBSERVED=PREDICTED
GRAPH SCALE EXTENDS FROM ********* TO *********
X - FLOW (cfs)
Y - PHOSPHATES lbs/day

PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....            17452.92308
YMEAN.....            ***********
INTERCEPT (A VALUE)...461718.52185
CORRELATION COEF......      0.95690
F
VALUE
542.76099

SOURCE OF VARIATION                    DEGREE OF
                                        FREEDOM
DUE TO REGRESSION..............            1
DEVIATION ABOUT REGRESSION....            50
                    TOTAL....             51

GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM ********** TO **********
```

PLOT OF OBSERVED AND PREDICTED VALUES.



XMEAN..... 4015.87500
YMEAN..... 914560.34562
INTERCEPT (A VALUE)... 57732.14153
CORRELATION COEF...... 0.93356

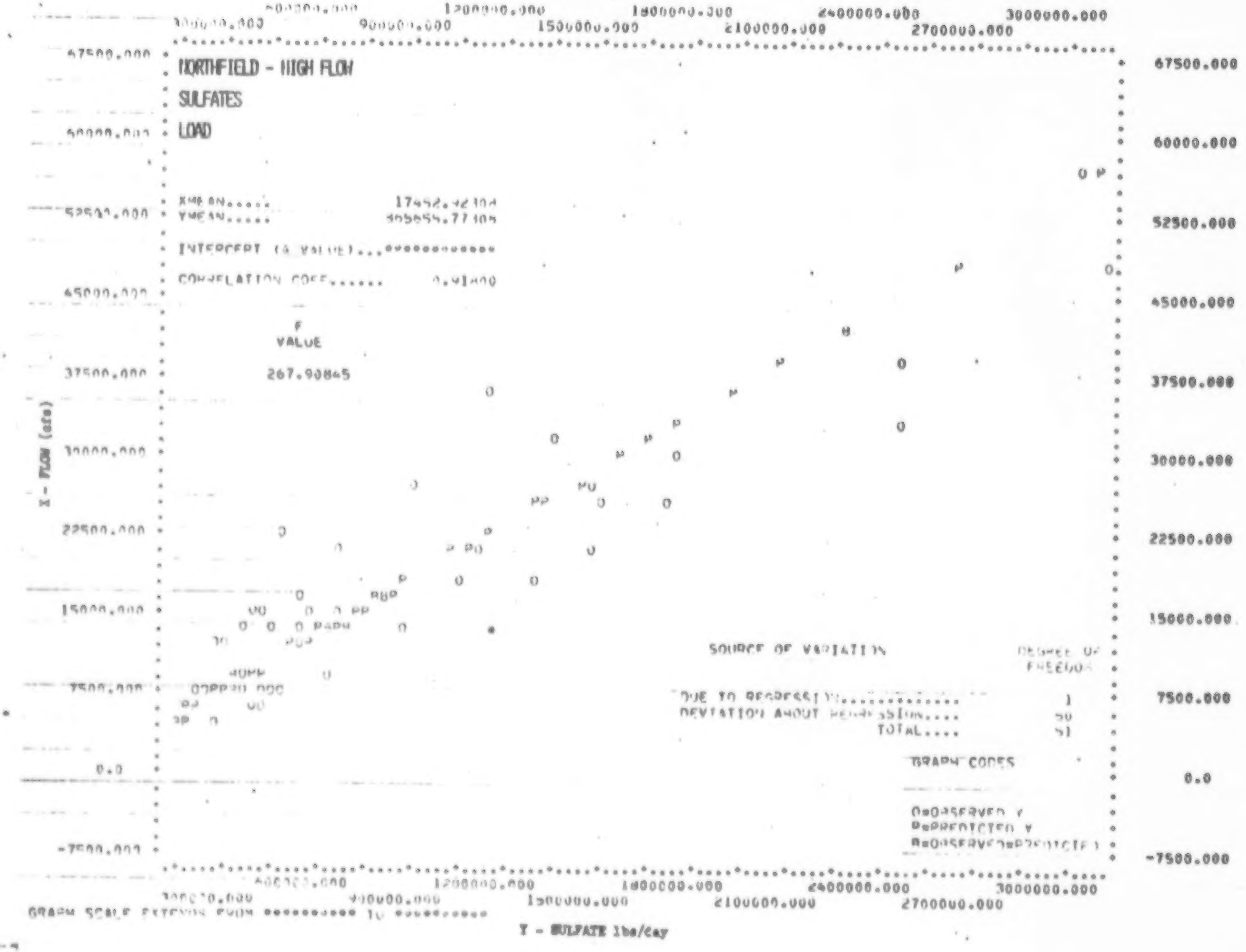
F VALUE 312.05420

SOURCE OF VARIATION	DEGREE OF FREEDOM
DUE TO REGRESSION..............	1
DEVIATION ABOUT REGRESSION....	46
TOTAL.....	47

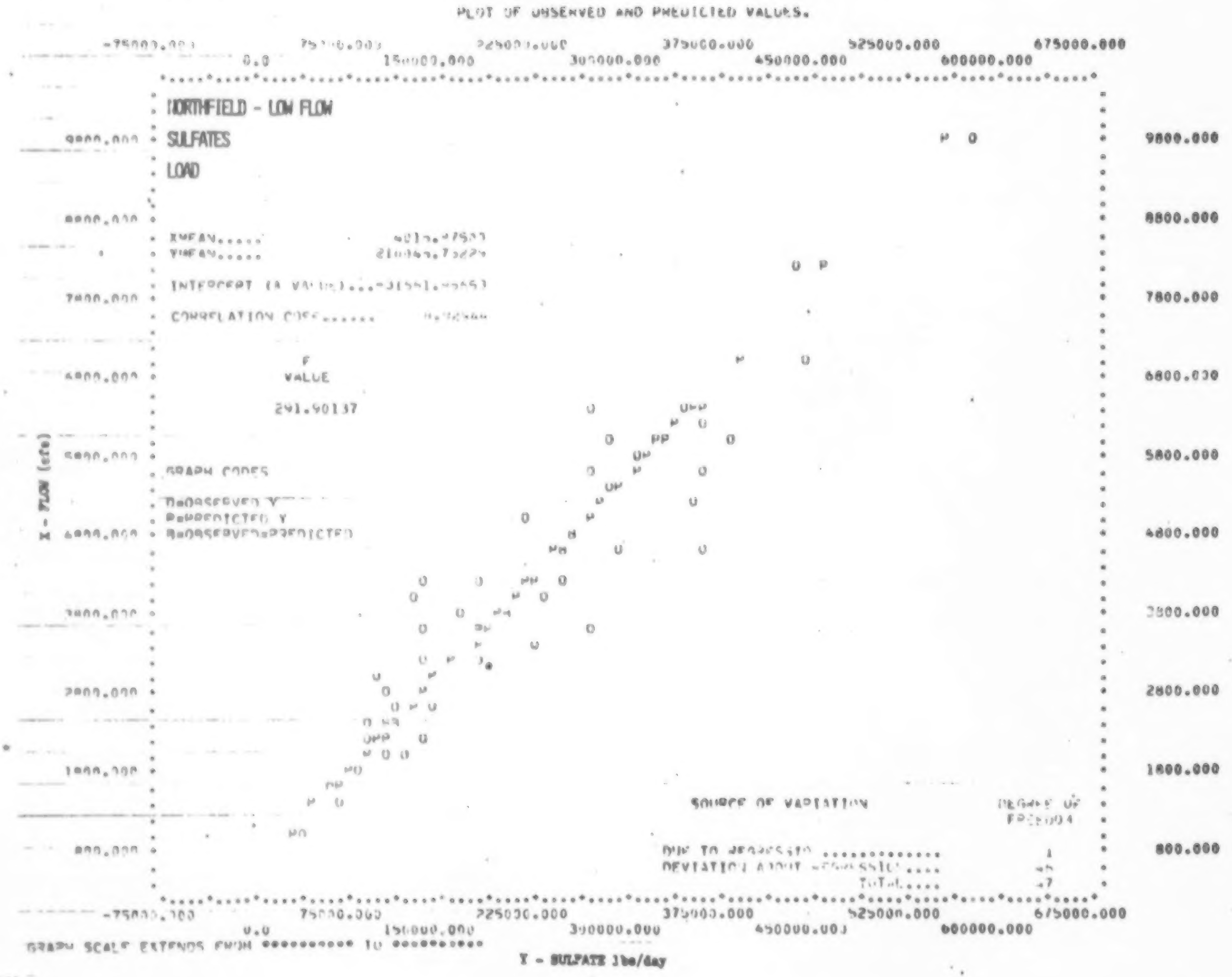
GRAPH CODES

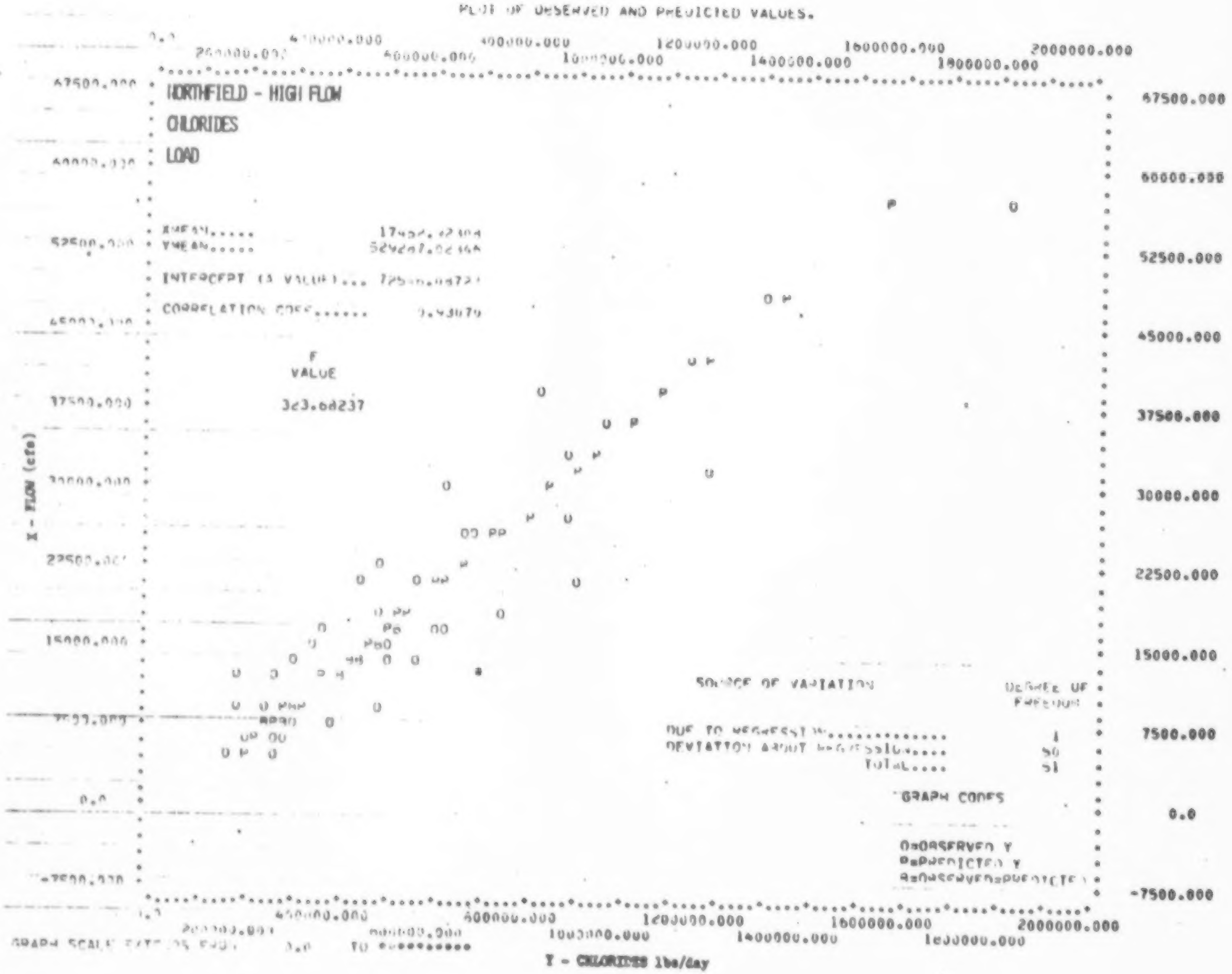
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED

PLOT OF OBSERVED AND PREDICTED VALUES.

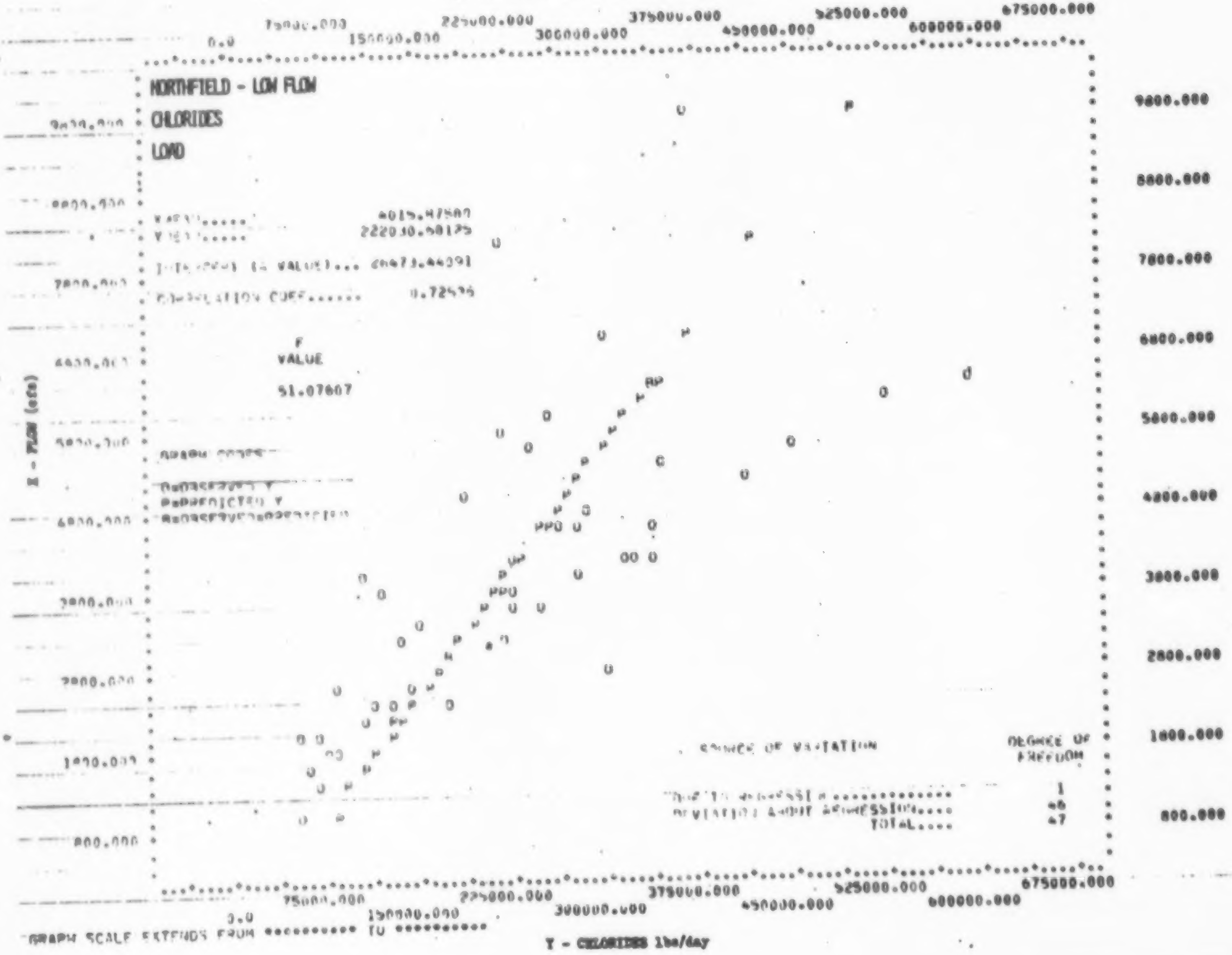


```
XMEAN......                17452.42104
YMEAN......               405655.77105

INTERCEPT (A VALUE)...************

CORRELATION COEF.......        0.91800

          F
        VALUE

      267.90845

                    SOURCE OF VARIATION              DEGREE OF
                                                      FREEDOM

                 DUE TO REGRESSION.................      1
                 DEVIATION ABOUT REGRESSION.....        50
                                     TOTAL.....         51

                                   GRAPH CODES

                                   O=OBSERVED Y
                                   P=PREDICTED Y
                                   B=OBSERVED=PREDICTED

GRAPH SCALE EXTENDS FROM ********** TO **********
```

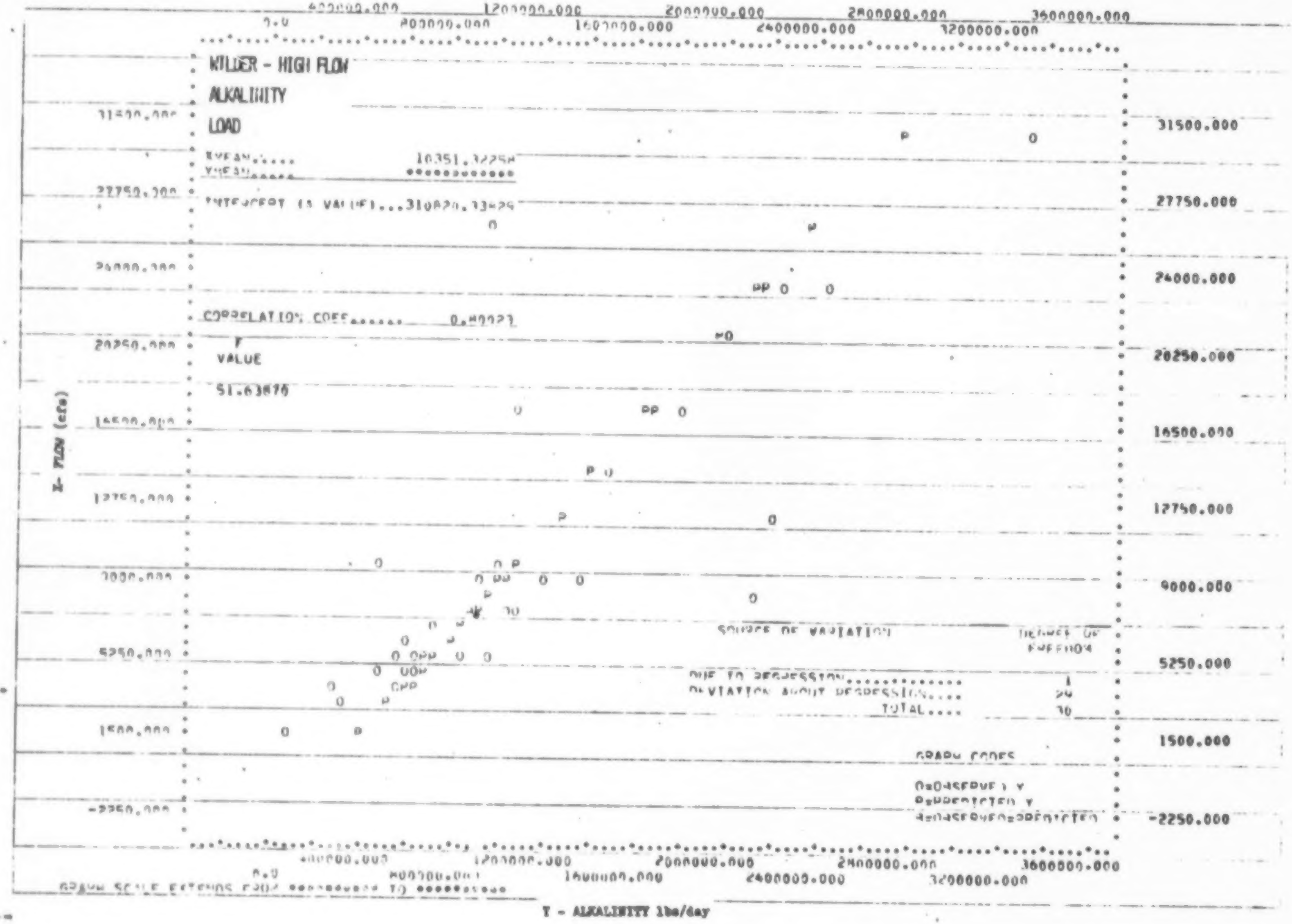
PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - LOW FLOW
SULFATES
LOAD
XMEAN......
YMEAN......
INTERCEPT (A VALUE)...
CORRELATION COEF.......
F
VALUE
241.90137
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION ....
DEVIATION ABOUT REGRESSION ....
TOTAL....
1
46
47
-75000.000
0.0
75000.000
150000.000
225000.000
300000.000
375000.000
450000.000
525000.000
600000.000
675000.000
9800.000
8800.000
7800.000
6800.000
5800.000
4800.000
3800.000
2800.000
1800.000
800.000
X - FLOW (cfs)
Y - SULFATE lbs/day
GRAPH SCALE EXTENDS FROM ********** TO **********


PLOT OF OBSERVED AND PREDICTED VALUES.
NORTHFIELD - HIGH FLOW
CHLORIDES
LOAD
XMEAN...... 17452.42304
YMEAN...... 524267.02468
INTERCEPT (A VALUE)... 725[illegible]
CORRELATION COEF....... 0.93079
F
VALUE
323.68237
SOURCE OF VARIATION
DEGREE OF FREEDOM
DUE TO REGRESSION............... 1
DEVIATION ABOUT REGRESSION..... 50
TOTAL.... 51
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
0.0
200000.000
400000.000
600000.000
800000.000
1000000.000
1200000.000
1400000.000
1600000.000
1800000.000
2000000.000
67500.000
60000.000
52500.000
45000.000
37500.000
30000.000
22500.000
15000.000
7500.000
0.0
-7500.000
X - FLOW (cfs)
Y - CHLORIDES lbs/day
GRAPH SCALE EXTENDS FROM 0.0 TO *********

PLOT OF OBSERVED AND PREDICTED VALUES.

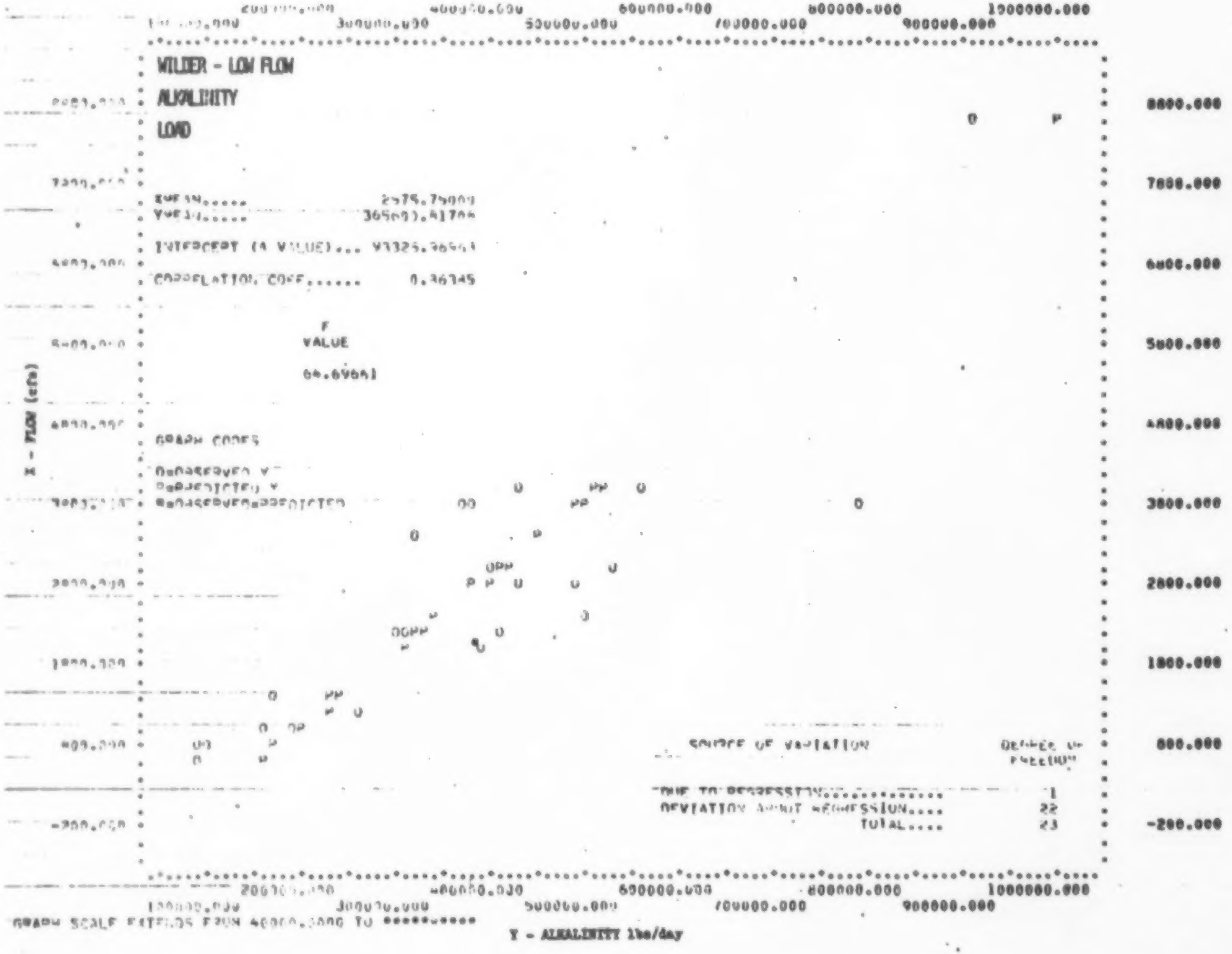


PLOT OF OBSERVED AND PREDICTED VALUES.



```
WILDER - HIGH FLOW
ALKALINITY
LOAD

XMEAN.....        10351.32258
YMEAN.....        *************

INTERCEPT (A VALUE)...310820.33829

CORRELATION COEF......    0.80021

F
VALUE
51.63870

SOURCE OF VARIATION                          DEGREE OF
                                              FREEDOM
DUE TO REGRESSION...............                1
DEVIATION ABOUT REGRESSION.....                29
                          TOTAL....            30

                                   GRAPH CODES

                                   O=OBSERVED Y
                                   P=PREDICTED Y
                                   *=OBSERVED=PREDICTED
```

PLOT OF OBSERVED AND PREDICTED VALUES.

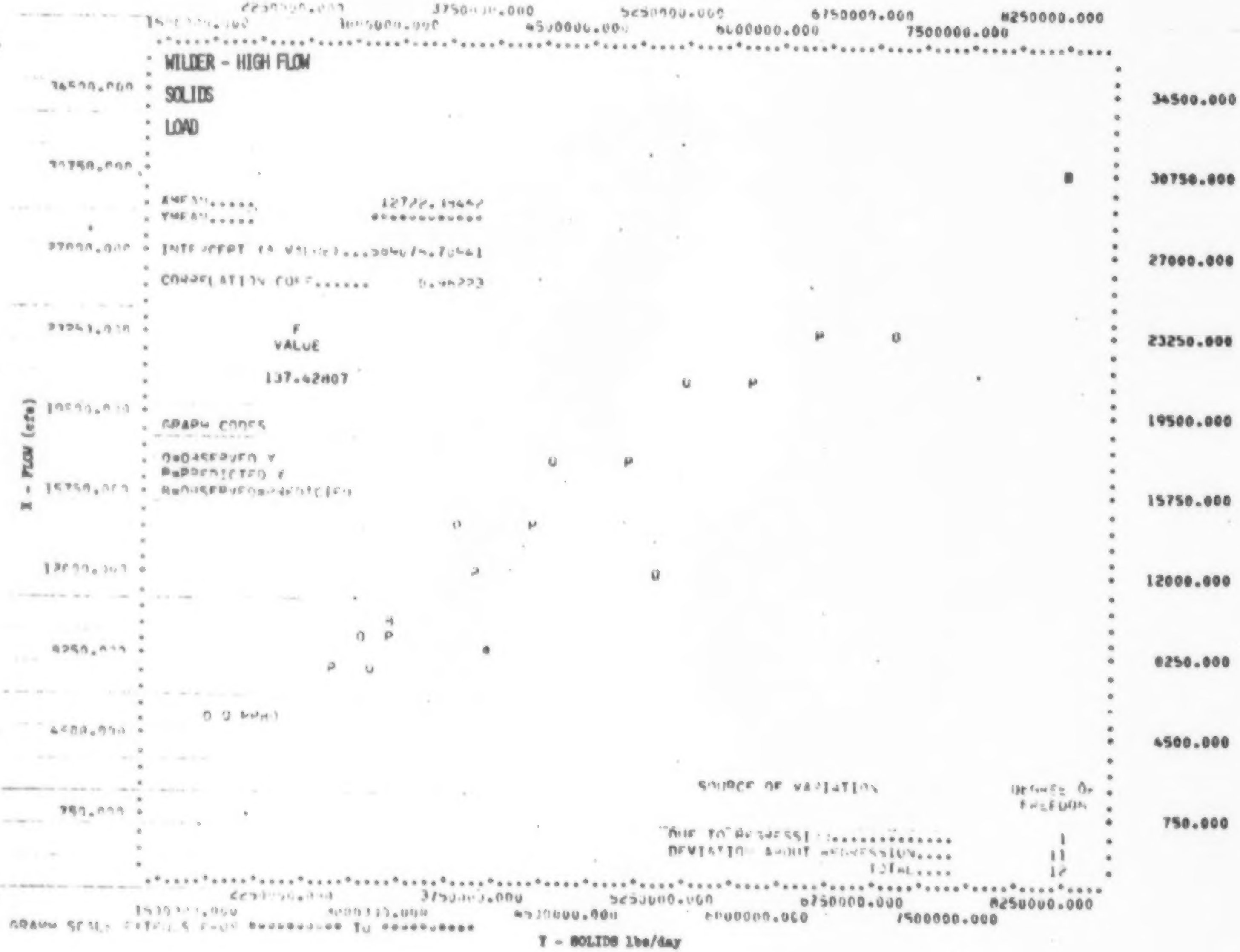


```
XMEAN.....                2575.75000
YMEAN.....              365091.41706

INTERCEPT (A VALUE)... 93325.36561

CORRELATION COEF.......      0.36345

                    F
                  VALUE

                 64.69661

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
*=OBSERVED=PREDICTED
```

```
SOURCE OF VARIATION                    DEGREE OF
                                        FREEDOM

DUE TO REGRESSION...............           1
DEVIATION ABOUT REGRESSION....            22
                     TOTAL....            23
```

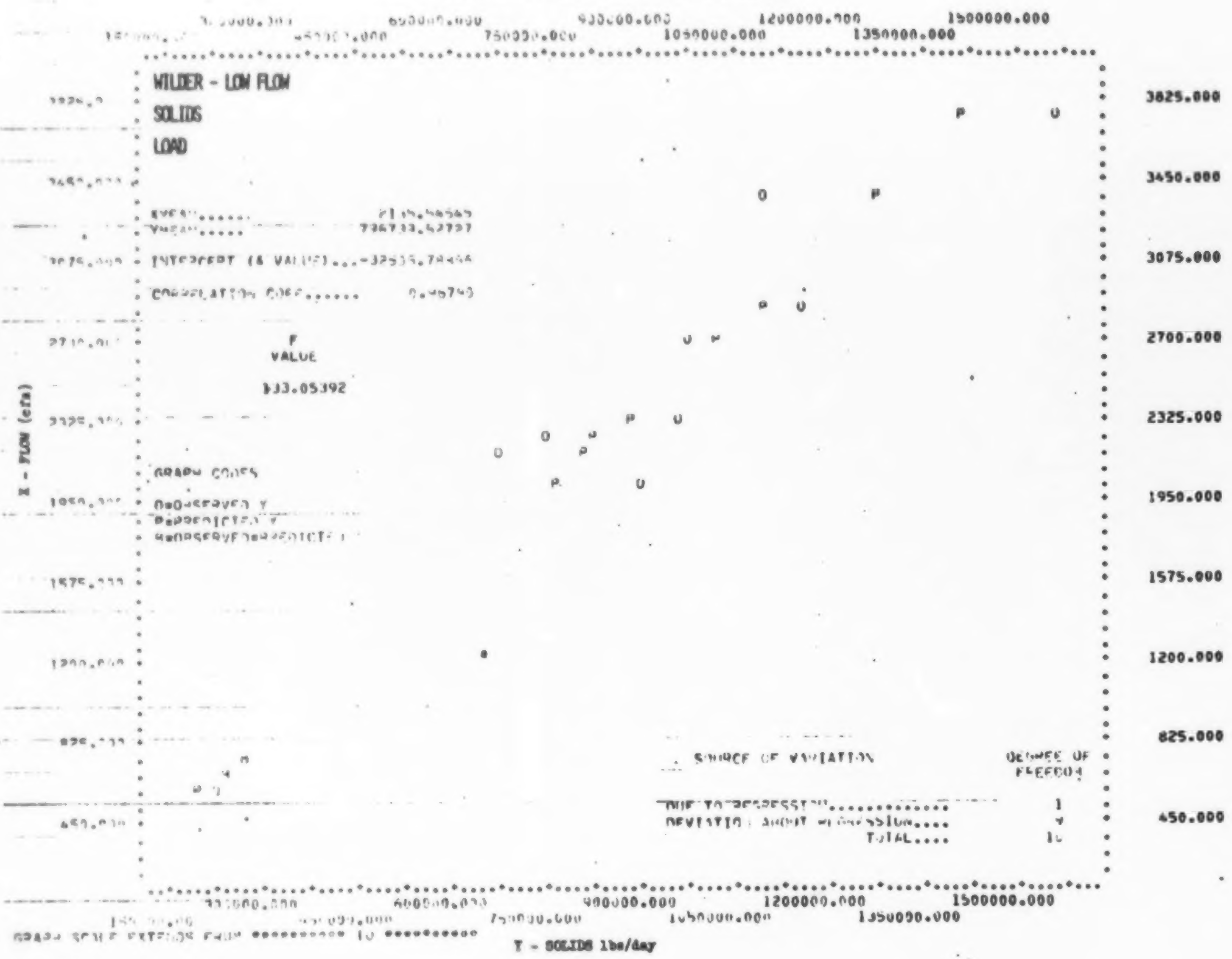
GRAPH SCALE EXTENDS FROM 40000.3000 TO **********

PLOT OF OBSERVED AND PREDICTED VALUES.



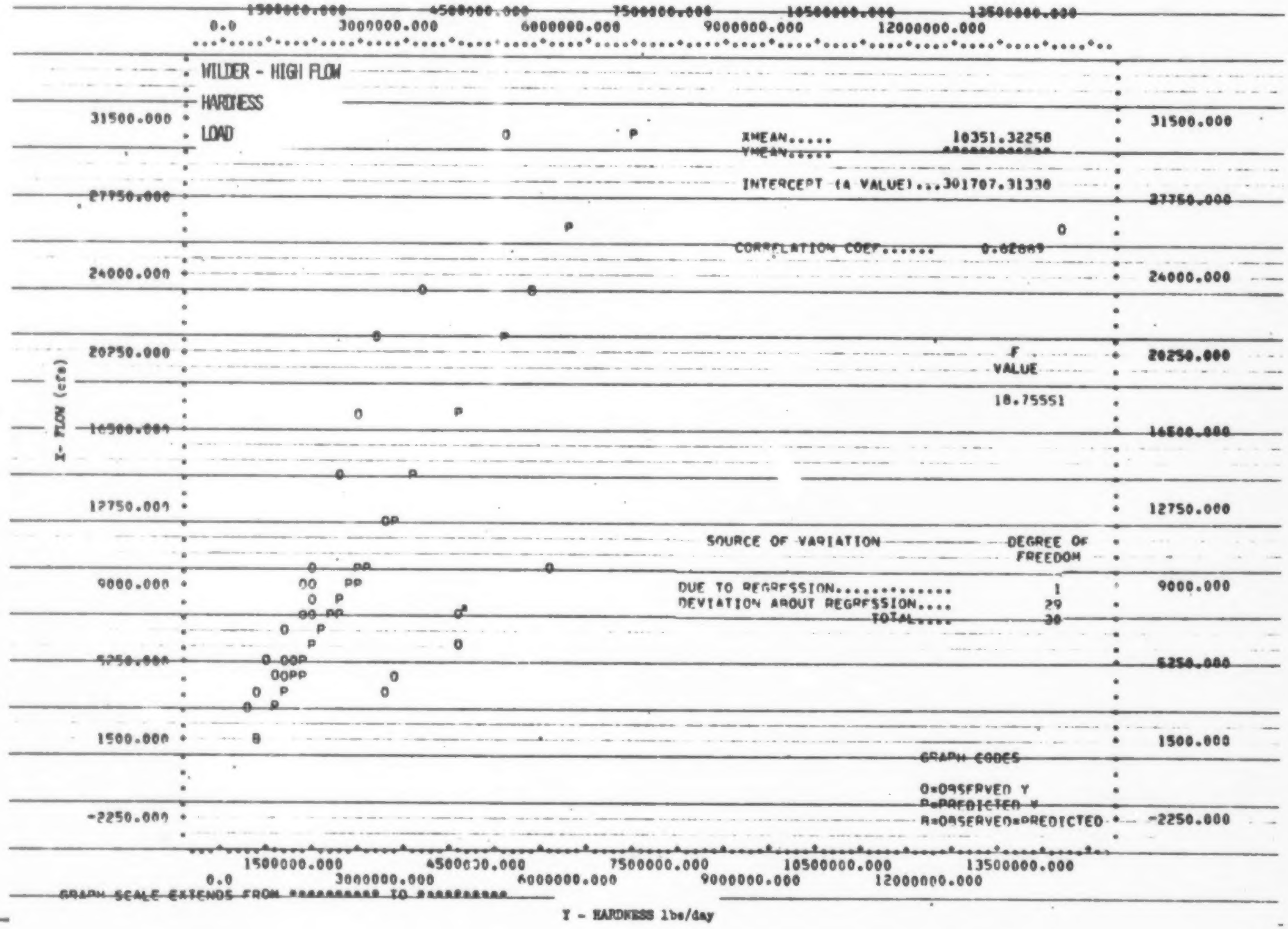
```
XMEAN.....                12722.19462
YMEAN.....                ***********

INTERCEPT (A VALUE)...-384074.70541

CORRELATION COEF.......     0.96223

          F
        VALUE

      137.42807

0 0 PPM)

            SOURCE OF VARIATION                  DEGREE OF
                                                  FREEDOM

        DUE TO REGRESSION................            1
        DEVIATION ABOUT REGRESSION....              11
                            TOTAL....               12

GRAPH SCALE EXTENDS FROM ********** TO **********
```

PLOT OF OBSERVED AND PREDICTED VALUES.



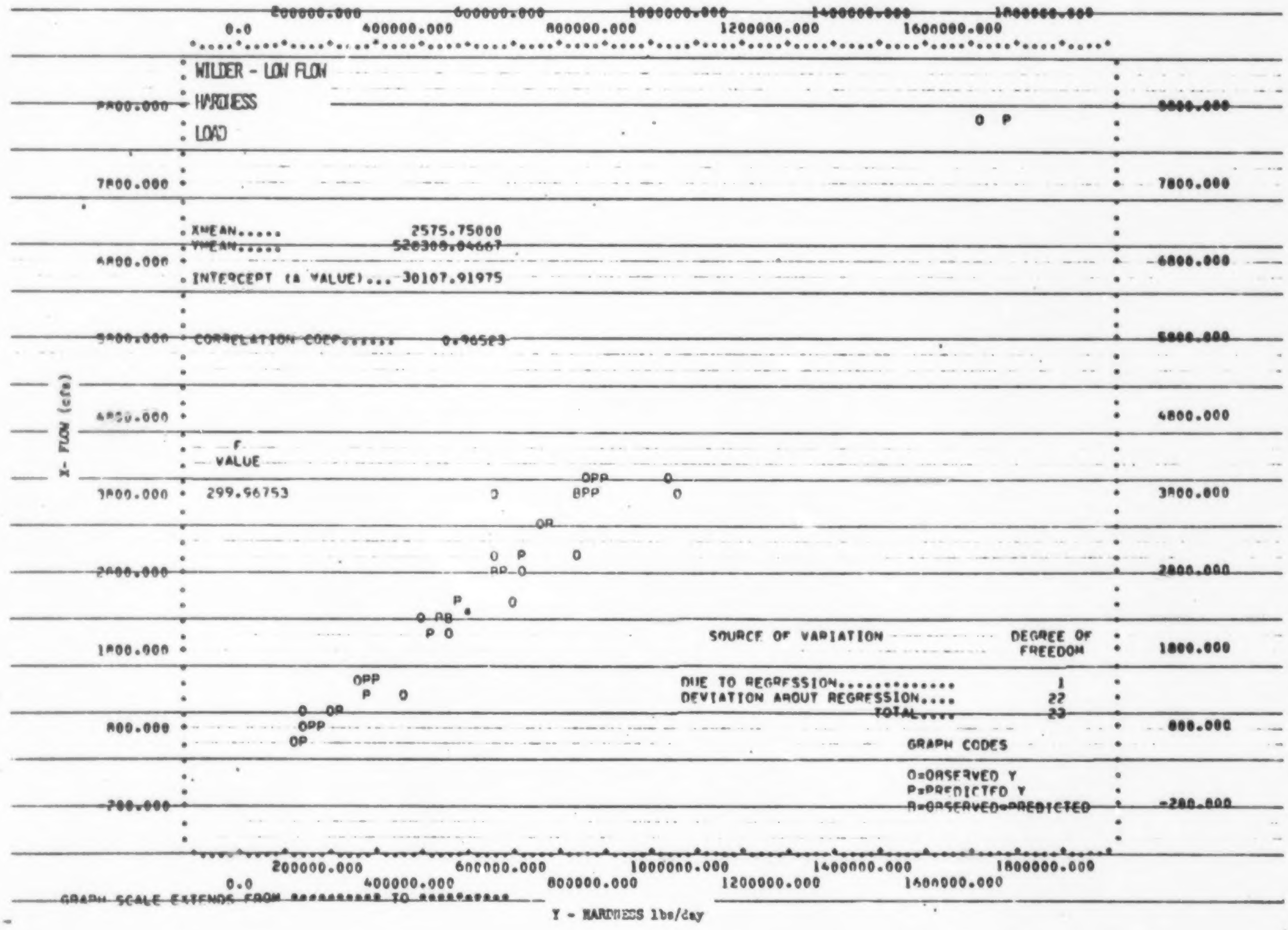
```
XMEAN......                  2135.56565
YMEAN.....                 736733.62737

INTERCEPT (A VALUE)...-32535.78446

CORRELATION COEF......       0.96743

         F
       VALUE

     133.05392

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
M=OBSERVED=PREDICTED

   SOURCE OF VARIATION                      DEGREE OF
                                             FREEDOM

DUE TO REGRESSION................                1
DEVIATION ABOUT REGRESSION....                   9
                         TOTAL....              10

GRAPH SCALE EXTENDS FROM ********** TO **********
```

PLOT OF OBSERVED AND PREDICTED VALUES.



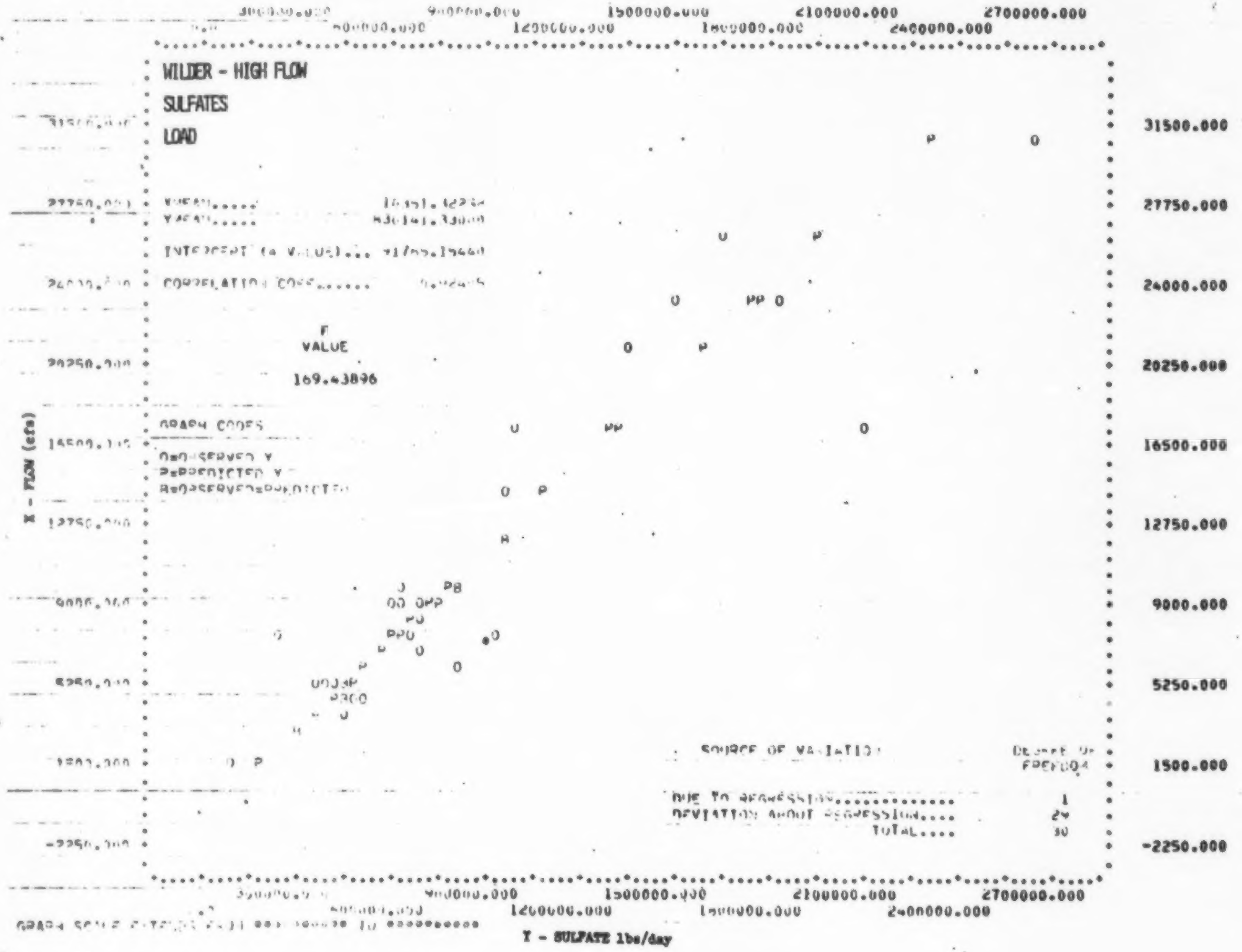
```
XMEAN.....                10351.32258
YMEAN.....                [illegible]

INTERCEPT (A VALUE)...301707.31330

CORRELATION COEF.......      0.62089

                                F
                              VALUE

                             18.75551

SOURCE OF VARIATION                  DEGREE OF
                                      FREEDOM

DUE TO REGRESSION..............          1
DEVIATION ABOUT REGRESSION....          29
                        TOTAL.....      30

                GRAPH CODES

                O=OBSERVED Y
                P=PREDICTED Y
                B=OBSERVED=PREDICTED
```

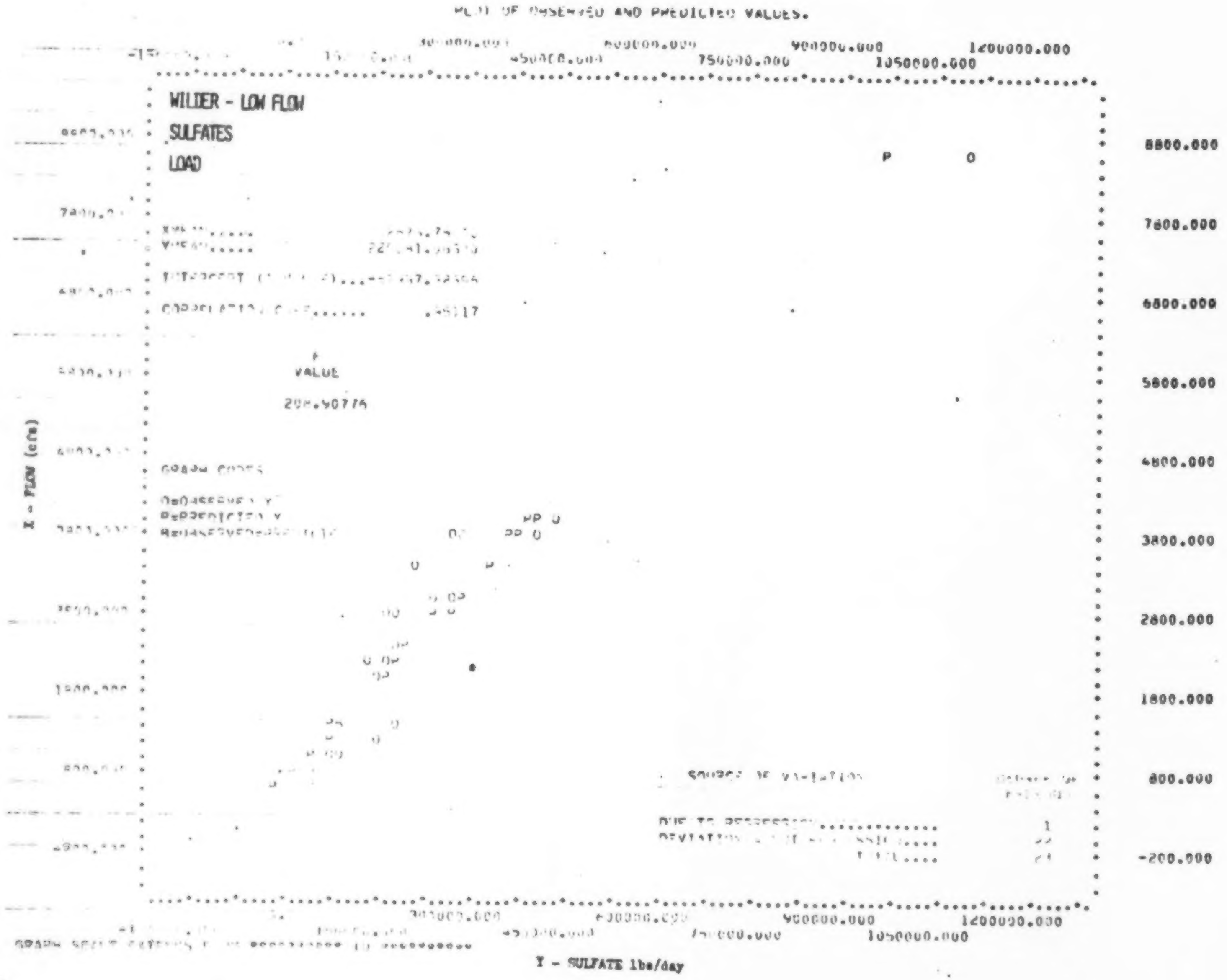
PLOT OF OBSERVED AND PREDICTED VALUES.



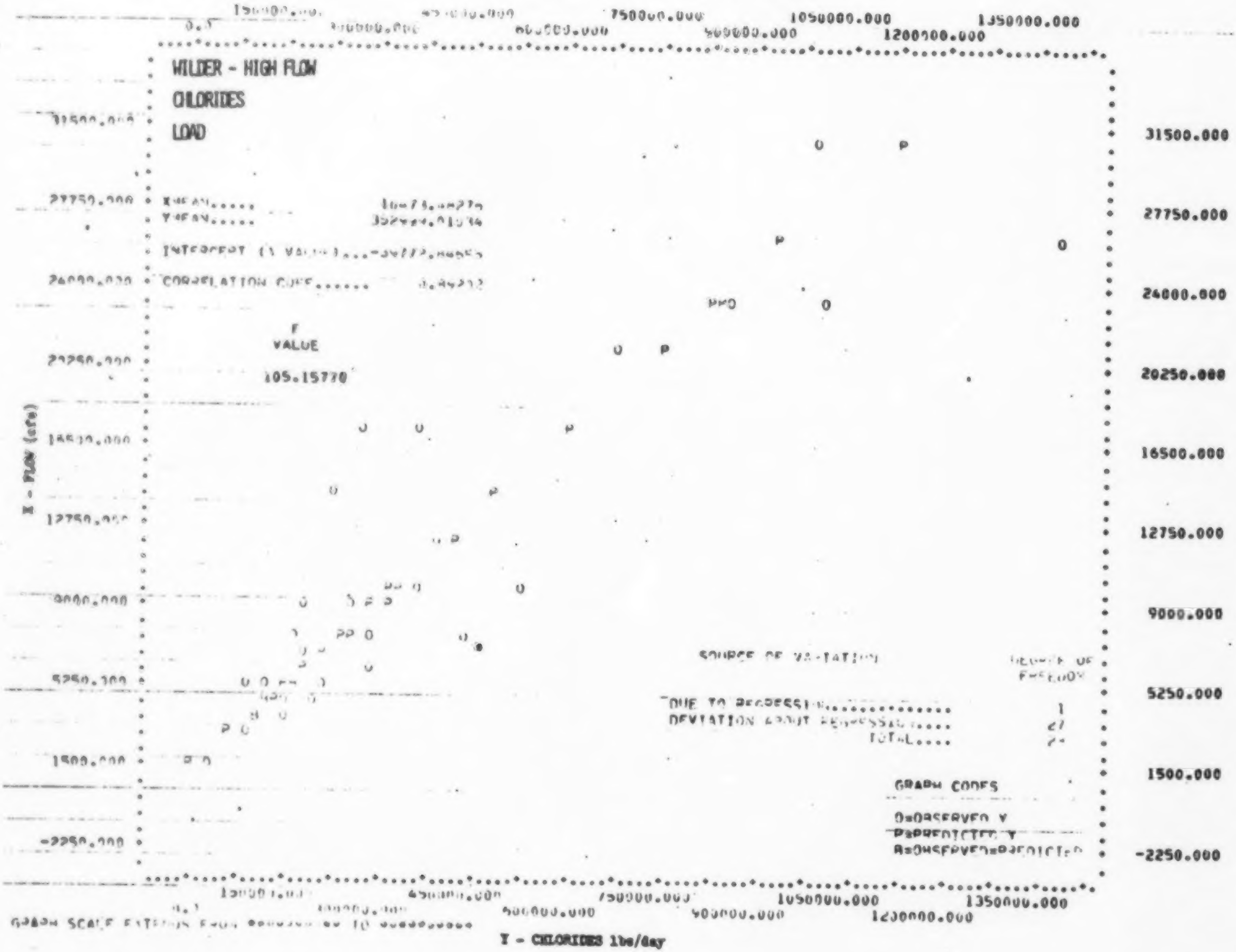
```
XMEAN.....                  2575.75000
YMEAN.....                520309.04667
INTERCEPT (A VALUE)...   30107.91975

CORRELATION COEF.......      0.96523

F
VALUE
299.96753

SOURCE OF VARIATION                    DEGREE OF
                                        FREEDOM

DUE TO REGRESSION...............            1
DEVIATION ABOUT REGRESSION....             22
                     TOTAL.....             23

                     GRAPH CODES

                     O=OBSERVED Y
                     P=PREDICTED Y
                     B=OBSERVED=PREDICTED
```

PLOT OF OBSERVED AND PREDICTED VALUES.



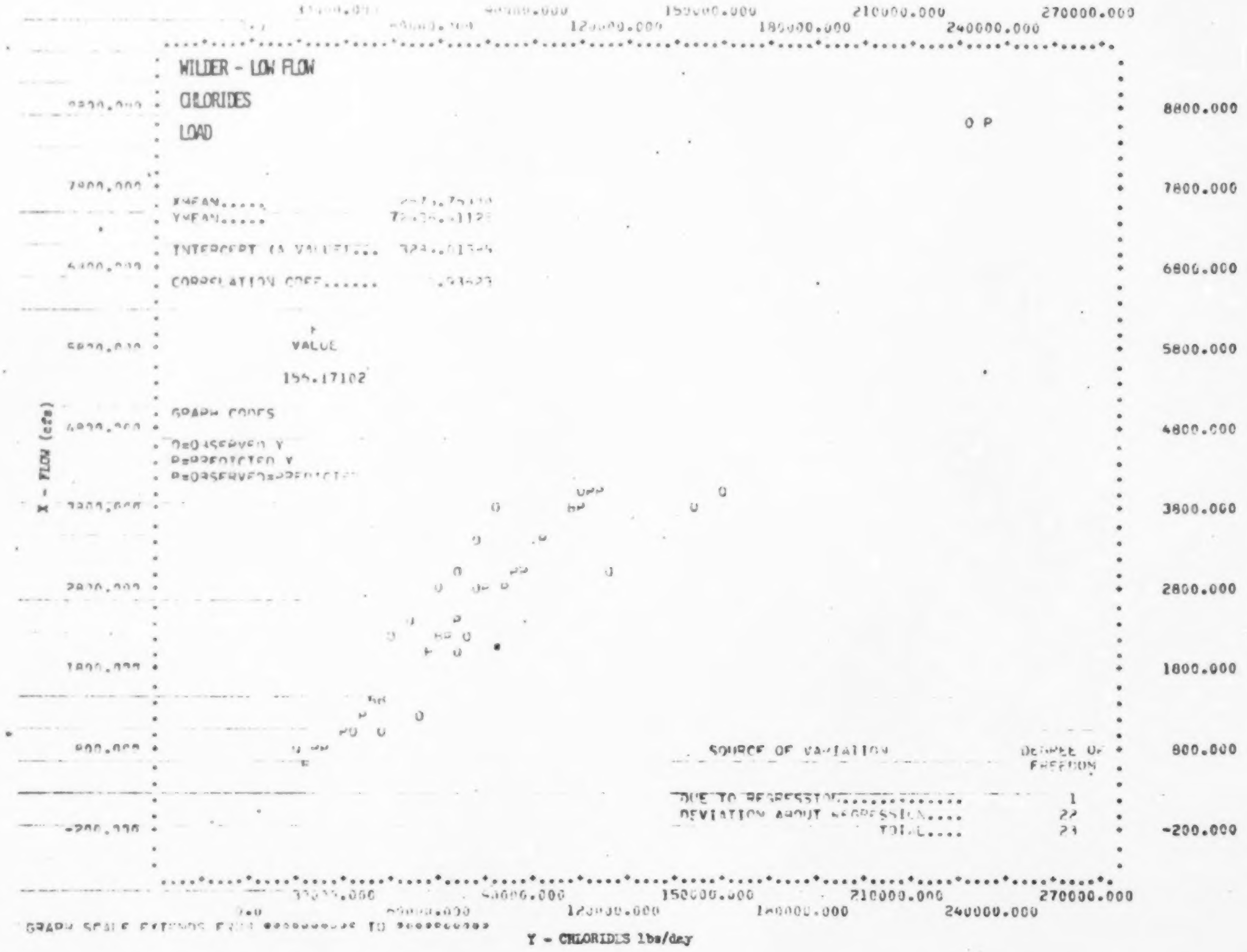

PLOT OF OBSERVED AND PREDICTED VALUES.
WILDER - LOW FLOW
SULFATES
LOAD
CORRELATION COEF....... .95117
F
VALUE
208.90776
GRAPH CODES
O=OBSERVED Y
P=PREDICTED Y
SOURCE OF VARIATION
DUE TO REGRESSION
DEVIATION
TOTAL
1
300000.000
450000.000
600000.000
750000.000
900000.000
1050000.000
1200000.000
8800.000
7800.000
6800.000
5800.000
4800.000
3800.000
2800.000
1800.000
800.000
-200.000
X - FLOW (cfs)
Y - SULFATE lbs/day

PLOT OF OBSERVED AND PREDICTED VALUES.



```
X MEAN......           1[illegible]
Y MEAN......           352[illegible]

INTERCEPT (A VALUE)...-[illegible]

CORRELATION COEF......    0.[illegible]

      F
    VALUE

  105.15770

SOURCE OF VARIATION                    DEGREE OF
                                        FREEDOM

DUE TO REGRESSION...............            1
DEVIATION ABOUT REGRESSION.....            27
                       TOTAL....            [illegible]

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

PLOT OF OBSERVED AND PREDICTED VALUES.



```
XMEAN.....                [illegible]
YMEAN.....                [illegible]

INTERCEPT (A VALUE)...    [illegible]

CORRELATION COEF......    .93623

          F
        VALUE

      155.17102

GRAPH CODES

O=OBSERVED Y
P=PREDICTED Y
B=OBSERVED=PREDICTED
```

```
SOURCE OF VARIATION                    DEGREE OF
                                        FREEDOM

DUE TO REGRESSION..............            1
DEVIATION ABOUT REGRESSION....            22
                        TOTAL....          23
```

GRAPH SCALE EXTENDS FROM [illegible] TO [illegible]